THE STAR THAT CHANGED THE COSMOS p. 54

AUGUST 2022

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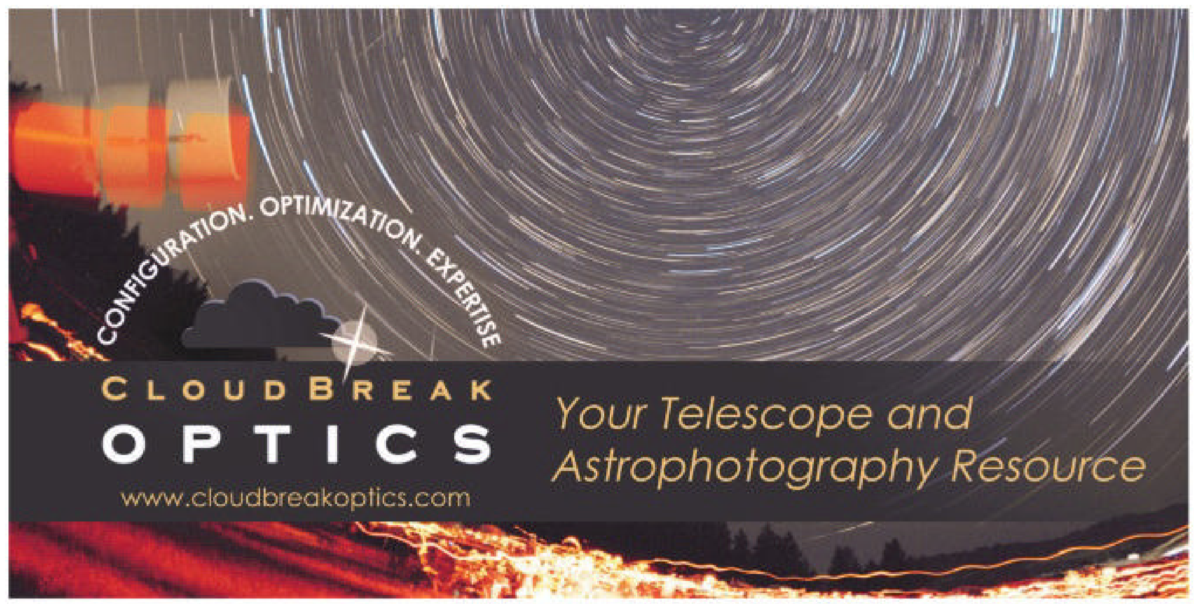
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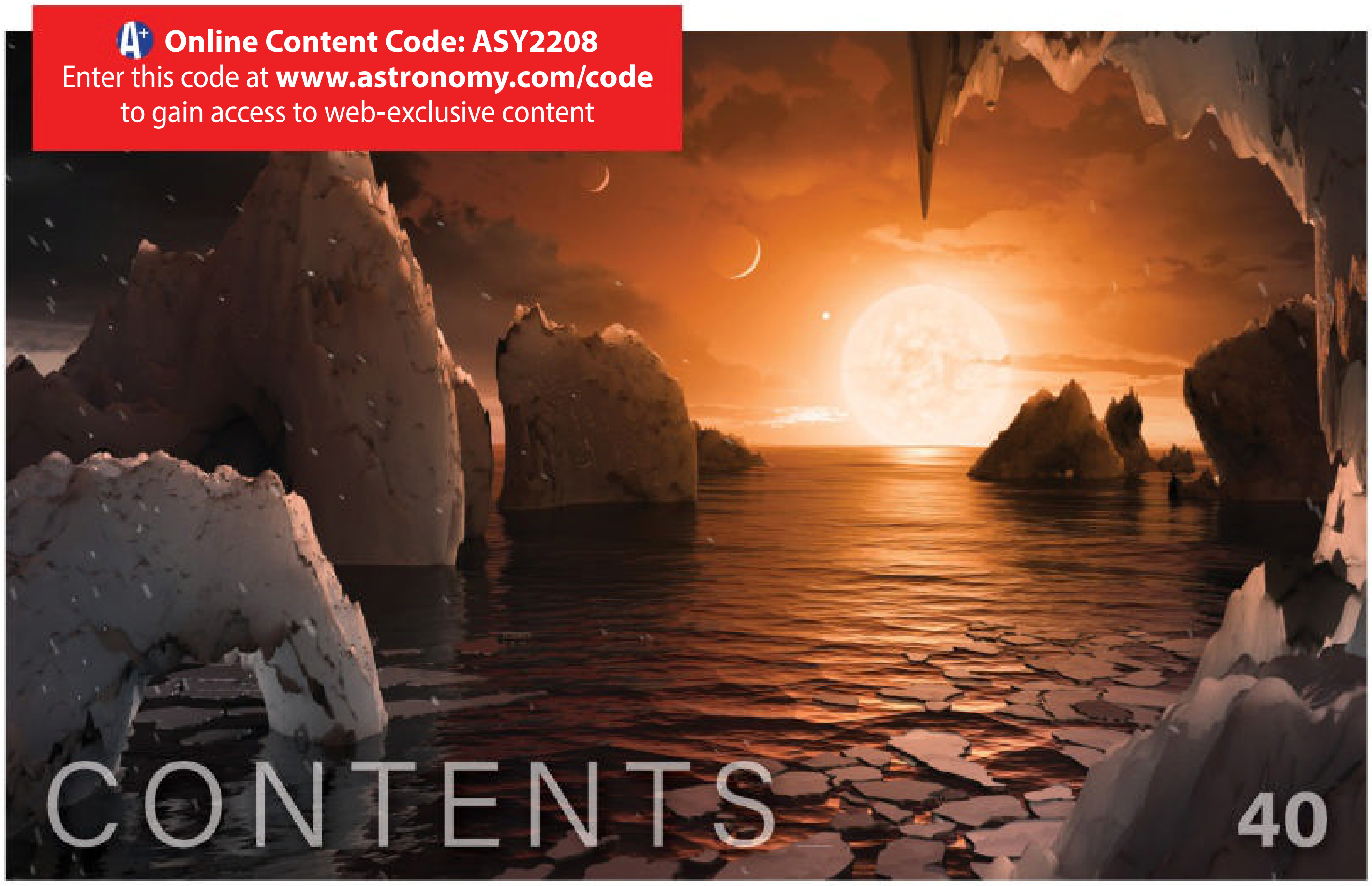

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ON THE COVER

Cloud belts swirl around Jupiter's southern hemisphere in this image captured by Juno Dec. 16, 2017.

ENHANCED IMAGE BY KEVIN M. GILL (CC-BY) BASED ON IMAGES PROVIDED COURTESY OF NASA/JPL-CALTECH/SWRI/MSSS.

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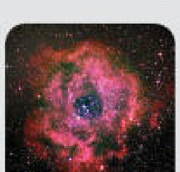

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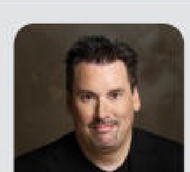

Dave's Universe
The inside scoop from the editor.

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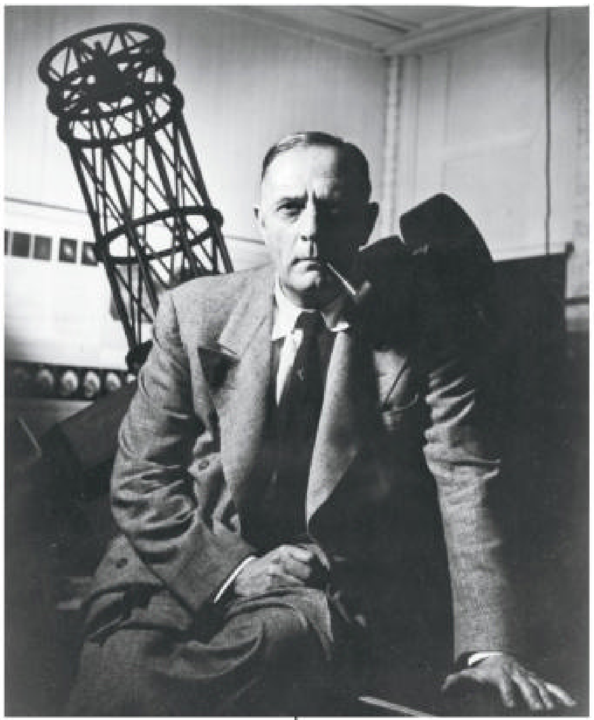
A very special star



Edwin Hubble poses with a model of the telescope he used to unlock the nature of galaxies.
HUB 1033 (11), EDWIN POWELL HUBBLE PAPERS, THE HUNTINGTON LIBRARY, SAN MARINO, CALIFORNIA

Edwin Hubble was neither the most accomplished astronomer on Earth nor the most well-liked by his colleagues. Yet, in the fall of 1923, he discovered a special star that turned our understanding of the cosmos on its head. On the night of October 5/6, using the 100-inch Hooker Telescope at Mount Wilson Observatory outside Los Angeles, Hubble recorded a deep exposure of what was then called the Andromeda Nebula. He was intensely curious about so-called spiral nebulae: Were they clouds of gas and stars within our galaxy, or very distant, mysterious objects?

Hubble was elated with his glass-plate negative. He believed he had found a nova, an exploding star, within the nebula, and he marked it with an N. Subsequent checking back at his office, however, nearly made him fall out of his chair. The star demonstrated a regular and well-known pattern of dimming and brightening: It was a Cepheid variable. He changed the marking to "VAR!" The star's incredibly faint nature, at around 19th magnitude, meant the "nebula" was immensely far away. In his landmark observation, Hubble had discovered the nature of galaxies and the first clues to the huge cosmic distance scale. Hubble thought what could then be renamed the Andromeda Galaxy was a million light-years off, three times larger than the previously imagined size of the whole universe. (We now know it lies 2.5 million light-years away.)

This legendary star has received scant attention since the days of Hubble, but astronomy enthusiast Rod Pommier, a frequent contributor to *Astronomy*, set out to hunt for the star, succeeding in imaging it with his 14-inch scope. I know that a few others, notably Tony Hallas, have also imaged this star, which has come to be known as M31-V1.

Rod's story of cosmic discovery (page 54), retracing the steps of Hubble's great discovery, will open your eyes to the amazing capabilities amateur astronomers now have with their telescopes and digital equipment, ready to be unlimbered on any given dark night.

Yours truly,

David J. Eicher
Editor

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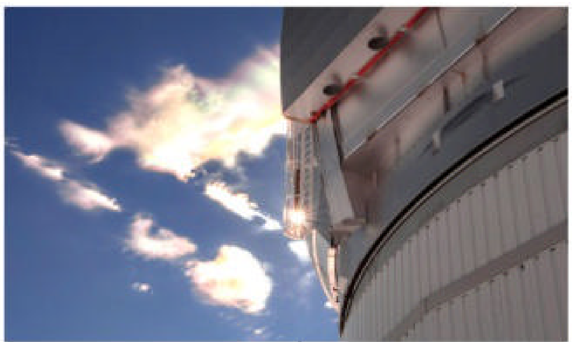

A rainbow appears on clouds above the Gemini South telescope in Chile. INTERNATIONAL GEMINI OBSERVATORY/NOIRLAB/NSF/AURA/MANUEL PAREDES

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Rain and shine

I've just read Stephen O'Meara's April 2022 column, "The impropriety of rainbows." I was intrigued by the fact that many cultures refer to rain while the Sun is in the sky as a monkey's wedding (or some animal's wedding). In Portuguese, there are also two popular sayings about rain and Sun relative to someone's wedding. When it's raining and the Sun comes back, we say: *Chuva com sol, casamento de espanhol*, meaning "Raining with Sun, Spanish wedding." When it's sunny and it starts raining, we say: *Sol com chuva, casamento de viúva*, meaning "Sun with rain, widow's wedding."
—Lucca Vanoni Ruggiero, São Paulo, Brazil

Reading the sky

Raymond Shubinski brought back some fond memories with his "Check out these classic sky guides" piece (April 2022). My copies of Norton's and Olcott's hardcover books are somewhat beyond well-worn. However, I would like to add two I personally consider all-time bests for beginners: *The Edmund Sky Guide* by Terence Dickinson and Sam Brown, and the *Edmund Mag 5 Star Atlas*. As a youngster many years ago, I found these two 36-page books both engaging and comprehensive.
—Vance Purdy, Rancho Palos Verdes, CA

Errata

In the map titled "A Warped View," on page 59 of the February issue, the scale is given as +/-600,000 light-years. It is actually +/-60,000 light-years.

In the Paths of the Planets section of our March issue, the path of the Moon was depicted incorrectly, with the Moon going to the south of the sky's June solstice point and north of the December solstice point. The reverse is true: The Moon is currently south of the ecliptic around the December solstice point and north of it at the June solstice point.

The Ask Astro section of the March issue incorrectly stated that a Type Ia supernova results in the birth of a new stellar remnant. Instead, this type of supernova normally obliterates the white dwarf completely.

SNAPSHOT

HUBBLE SPIES THE FARTHEST STAR

A cosmic magnifying glass made it possible.

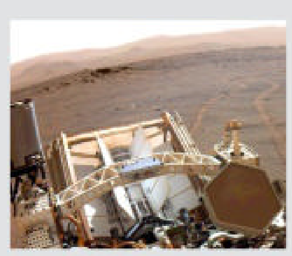
At the risk of sounding like a broken record, NASA's Hubble Space Telescope has broken another record. With the help of a phenomenon called gravitational lensing, the aging observatory recently captured this image of the most distant star ever seen, nicknamed Earendel.

"When the light that we see from Earendel was emitted, the universe was less than a billion years old," said Victoria Strait, a postdoc at the Cosmic Dawn Center in Copenhagen, in a press release. "At that time, it was 4 billion light-years away from the proto-Milky Way, but during the almost 13 billion years it took the light to reach us, the universe has expanded so that it is now a staggering 28 billion light-years away."

Earendel shines millions of times as brightly as the Sun and might have weighed as much as 500 times the mass of the Sun, though researchers think it was more likely between 50 and 100 solar masses. Either way, astronomers say Earendel lived fast and died young, blowing itself apart long, long ago. – JAKE PARKS

SCIENCE: NASA, ESA, BRIAN WELCH (JHU), DAN COE (STSCI); IMAGE PROCESSING: NASA, ESA, ALYSSA PAGAN (STSCI). BOTTOM FROM LEFT: NASA/JPL-CALTECH; NASA/KIM SHIFLETT; HARIKANE ET AL.

» HOT BYTES

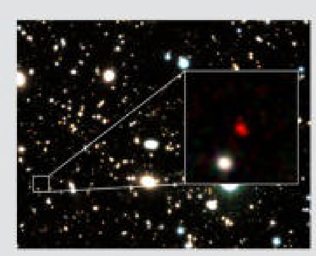


MAD DASH

More than a year after its arrival, NASA's Perseverance rover made a 31-martian-day-long beeline to an ancient river delta on the edge of Jezero Crater that scientists hope once housed microbial life.

HELIOPHYSICIST PASSES

Solar science pioneer Eugene Parker died March 15. In 2018, Parker became the first living person to witness the launch of a spacecraft bearing his name — NASA's Parker Solar Probe.



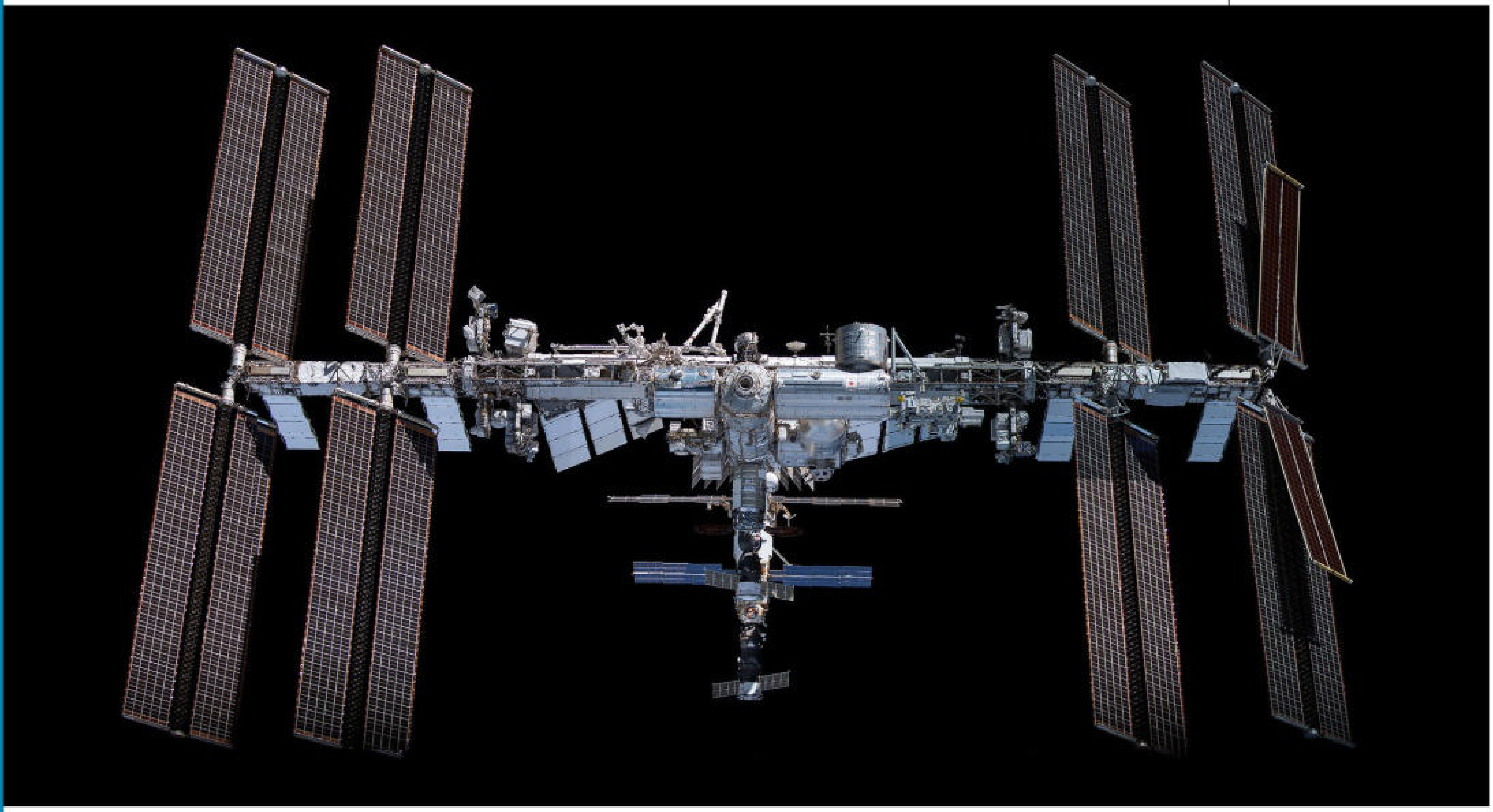
MOST DISTANT GALAXY

At 13.5 billion light-years, HD1 is the farthest known galaxy. Strangely, it has a surplus of light, suggesting it is home to either the earliest supermassive black hole or hypothetical Population III stars — the universe's first stars.

RUSSIA'S WAR IN UKRAINE REORDERS SPACE ALLIANCES

Fallout from international sanctions leaves Russia's space program isolated.

UP IN THE AIR. Russia has cast doubt on its future participation in the International Space Station, pictured here Nov. 8, 2021, from the SpaceX Crew Dragon *Endeavour*. NASA



The repercussions of Russia's invasion of Ukraine — the largest land war in Europe since World War II, still ongoing as of this writing — have extended not just beyond Ukraine's borders but also above Earth's atmosphere.

When Russia invaded Ukraine Feb. 24, much of the world responded by levying economic sanctions on Russia and rushing aid and weapons to Ukraine. In response, the Russian space agency Roscosmos cut ties and canceled agreements with a string of spacefaring nations. The war has also forced the international scientific community to weigh the moral cost of collaborations with Russia, pushing relationships forged after the Cold War beyond the breaking point.

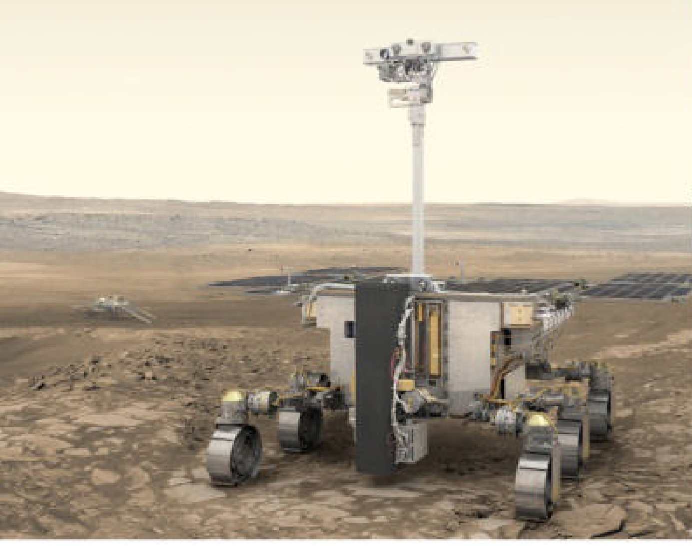
In one of the highest-profile breaks, the European Space Agency (ESA) announced March 17 it would suspend work on the ExoMars rover, which it built in a joint mission with Roscosmos. The rover had been scheduled to launch aboard a Russian Proton rocket from the Baikonur Cosmodrome later in 2022. Russia had also been set to provide the landing vehicle that would carry the rover to the martian surface.

"As an intergovernmental organization mandated to develop and implement space programs in full respect with European values, we deeply deplore the human casualties and tragic consequences of the aggression towards Ukraine," the agency said in a statement after a meeting of its ruling council March 17, adding that it is "fully aligned with the sanctions imposed on Russia by its Member States."

ESA officials are now exploring options to team up with other nations and agencies to finish the mission. The rover, named Rosalind Franklin, is "technically ready for launch," says ESA. But in May 3 comments reported by *SpaceNews* at a conference in Denver, ExoMars ESA project scientist Jorge Vago said that realistically, the rover would not launch before 2028.

FRAYING TIES

ExoMars isn't the only collaboration that has fallen by the wayside. In the days immediately after the invasion,



PLAN A. The ExoMars rover Rosalind Franklin explores the martian surface in this artist's concept. In the background at left lies the now-cancelled Russian-built lander. ESA/ATG MEDIALAB

Roscosmos responded to international sanctions by severing a series of ties with the U.S., U.K., and Europe.

On Feb. 26, Roscosmos Director General Dmitry Rogozin said Russia would halt Soyuz rocket launches from Europe's spaceport in French Guiana. Previously scheduled Soyuz launches of European payloads included Galileo satellites for Europe's global navigation system and ESA's Euclid infrared space telescope. ESA hopes to launch the craft on different rockets — perhaps the agency's own upcoming Ariane 6 or Vega-C launchers.

Also on Feb. 26, Rogozin declared NASA could no longer participate in Russia's Venera-D mission, a Venus orbiter and lander planned for 2029. (This was largely ceremonial, as no formal role for NASA had yet been agreed on.)

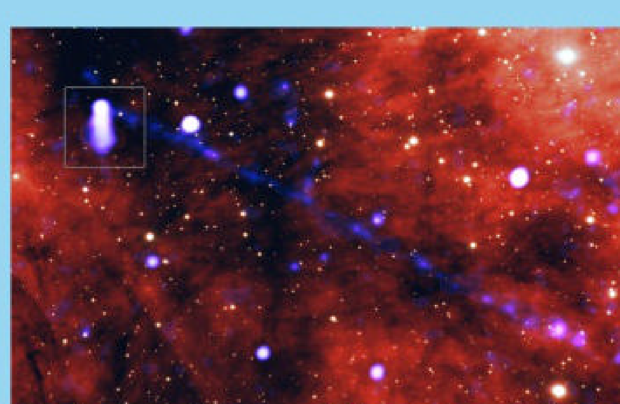
And on March 4, Rogozin canceled a contract for a series of launches with the London-based internet provider OneWeb, even as 36 of the company's craft sat loaded in a Soyuz rocket on a Baikonur launchpad. The cancellation came after Rogozin demanded March 2 that OneWeb guarantee its satellites would only be used for civilian purposes and that the U.K. divest its partial ownership of the company. Both demands were rebuffed. Later that month, OneWeb announced it had reached a deal with SpaceX to conduct future launches of its satellites.

One project that has remained outwardly unaffected by the war in Ukraine is the International Space Station (ISS), in which Russia is a key partner — for now. However, Rogozin has threatened to pull Russia out of the ISS and undock Russian modules and spacecraft. Russia contributed the station's service module, which is responsible for keeping the ISS aloft, periodically boosting its orbit to counteract drag from Earth's upper atmosphere.

In a Feb. 28 media teleconference, NASA's head of human spaceflight, Kathryn Lueders, said SpaceX and Northrop Grumman could potentially provide reboost capabilities. But, she added, it would still be difficult to operate the station without some Russian cooperation.

Russia's collapse in relations with the U.S. and Europe comes as it ramps up cooperation with China on plans for a lunar space station and base. If China remains willing to work with what is now a pariah state, the future of space exploration may look less like the global cooperative model of the ISS and more like a Cold War, with blocs of spacefaring nations. — MARK ZASTROW

Pulsar leaks antimatter



X-RAY: NASA/CXC/STANFORD UNIV/M. DE VRIES; OPTICAL: NSF/AURA/GEMINI CONSORTIUM

The pulsar J2030+4415 (J2030 for short) — a dense stellar remnant with a strong magnetic field and fast spin — is traveling through our galaxy at about 500,000 mph (800,000 km/h). This causes its winds, which contain both matter and antimatter, to trail behind it, while a bow shock of gas leads in front. But somehow, about 20 to 30 years ago, the bow shock slowed down and J2030 smashed into it, causing a particle leak. The result: a beam of matter and antimatter 40 trillion miles (64 trillion kilometers) long. This image, from research published March 25 in *The Astrophysical Journal*, suggests that pulsars could be partially responsible for the large swaths of positrons — the antimatter counterpart of the electron — that mysteriously dot the universe. — CAITLYN BUONGIORNO

QUICK TAKES

SLS SLIPS AGAIN

NASA called off a wet dress rehearsal for its new Moon rocket, the Space Launch System (SLS), due to a series of issues including a leaking hydrogen supply line and a faulty valve. The rocket's first uncrewed flight, Artemis 1, is now expected to launch no earlier than August.

NOT-SO-STANDARD MODEL

Scientists at Fermilab pinned the mass of the W boson, a fundamental force-carrying particle, to about 80 times the mass of a proton (with an unparalleled precision of 0.01 percent). This puts the measurement in tension with the Standard Model of physics.

STEP ASIDE STARLINK

On April 5, Amazon announced it had inked deals with three rocket companies for up to 83 launches over the next five years, which will deliver more than 3,200 satellites into low-Earth orbit to provide internet connectivity around the globe.

ALIEN ETHER

For the first time, astronomers have detected dimethyl ether — a precursor to larger organic molecules that can spur life — within the planet-forming disk around another star. With nine atoms, the compound is the largest yet found in such a disk.

LUNAR SENTRY

The Earth-Moon system could serve as an enormous gravitational-wave detector capable of picking up microhertz signals from the ancient universe. These waves would create tiny changes in the distance between the two bodies, which scientists currently track to within 0.04 inch (1 millimeter).

OLDER DRYAS

A new analysis of the 19-mile-wide (31 kilometers) Hiawatha Crater beneath Greenland's ice shows the impact scar is some 58 million years old. That means the impact responsible was not related to Younger Dryas — a period of global cooling some 12,000 years ago — as previously speculated. — J.P.

A strange FRB in a strange place

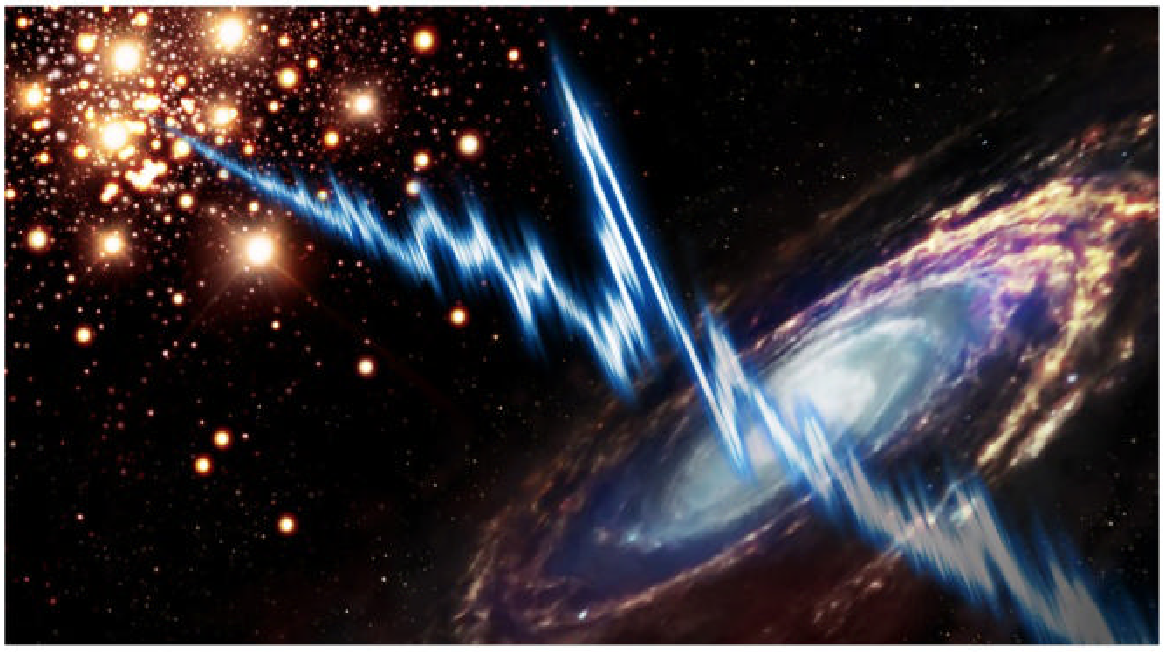
Fast radio bursts, or FRBs, are brief, intense flashes of radio waves believed to arise on extremely magnetic neutron stars called magnetars. One-off bursts are difficult to trace, but a few repeat, allowing researchers to more easily determine their origin. That's exactly what a team studying one repeater, called FRB 20200120E, accomplished — with unexpected results. Their work was published Feb. 23 in *Nature* and *Nature Astronomy*.

Bursts from FRB 20200120E are as short as 60 billionths of a second. That indicates they are coming from "a tiny volume in space, smaller than a soccer pitch," said team co-leader Kenzie Nimmo of the Netherlands Institute for Radio Astronomy (ASTRON) and the University of Amsterdam in a press release. The fact that the signal originates from such a small area supports the idea that FRBs come from magnetars, as neutron stars themselves are small: roughly the size of Manhattan.

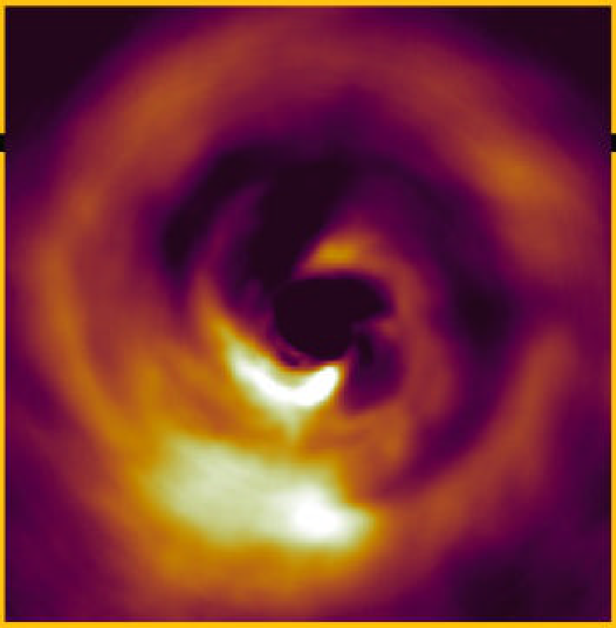
Using several radio telescopes, the team tracked FRB 20200120E to its origin. It lies in M81, just 12 million light-years away. That makes it the closest FRB to date. Even odder, the FRB is in a dense grouping of old stars called a globular cluster. Finding a magnetar — the product of short-lived stars — in this environment is unexpected, the team said. All other FRBs with known positions lie in regions of distant galaxies that house young, massive stars.

So, how did the magnetar powering FRB 20200120E form in such an unexpected place? There are two possibilities: first, a long-predicted but never-before-seen phenomenon called accretion-induced collapse. This is when a white dwarf pulls mass from a companion and tips over a cosmic weight limit, collapsing into a denser neutron star. Although posited to be rare in globular clusters, it's the simplest and likeliest explanation, the team says. Alternatively, perhaps FRB 20200120E is the result of a merger between two white dwarfs, two neutron stars, or one of each. Such mergers are more common in globular clusters and could create a neutron star.

For now, the mystery remains. And regardless of the answer, it indicates there are likely many ways to create the magnetars that power these strange signals. —ALISON KLESMAN



MYSTERIOUS ORIGINS. Researchers have traced a fast radio burst to a globular cluster full of old stars in a nearby galaxy. But the magnetars believed responsible for FRBs are young, raising questions of how it could have gotten there. ASTRON/DANIËLLE FUTSELAAR, ARTSOURCE.NL



PLANETBIRTH. The hot, glowing mass at the bottom of this image is a nascent planet. The central star, AB Aurigae, has been masked by the instrument that snapped the image at the Subaru Telescope in Hawaii. T. CURRIE/SUBARU TELESCOPE

PROTOPLANET SHAKES UP FORMATION THEORY

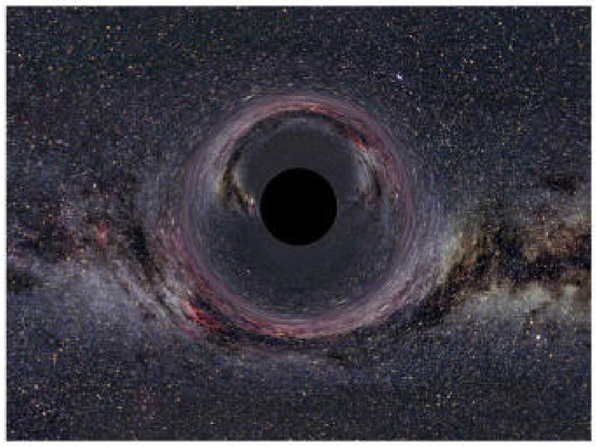
Astronomers have spotted a spectacular stellar maelstrom birthing a planet roughly nine times the mass of Jupiter.

The star is AB Aurigae, about 530 light-years away. Just a couple of million years old, it is still surrounded by a disk of leftover gas and debris — and a prominent hot clump at its outer fringes that appears to be a protoplanet.

The team verified this with observations from the 8.2-meter Subaru Telescope atop Mauna Kea in Hawaii and the Hubble Space Telescope, including data from Hubble's archives taken 13 years earlier. Their results were published April 4 in *Nature Astronomy*.

Especially unusual is the protoplanet's great distance from its star — roughly 8.6 billion miles (14 billion kilometers), or more than twice the distance of Pluto from our Sun. This is hard to square with the most popular model of planet formation, called core accretion, in which planetary cores begin forming when dust grains and pebble-sized bits of debris glom on to each other. The planet, named AB Aurigae b, is so far out from its star that there's likely not enough debris to form a large core.

This makes it powerful evidence for an alternate method of planet formation called disk instability, where large clumps of gas in the protoplanetary disk become unstable and collapse under their own gravity. This would form planets directly, similar to how stars are born. —M.Z.



INVISIBLE WANDERER. Astronomers may have detected a lone, or rogue, black hole by watching how its gravity bends the light of a background star. UTE KRAUS (BACKGROUND MILKY WAY PANORAMA: AXEL MELLINGER), INSTITUTE OF PHYSICS, UNIVERSITÄT HILDESHEIM

Found: A rogue black hole

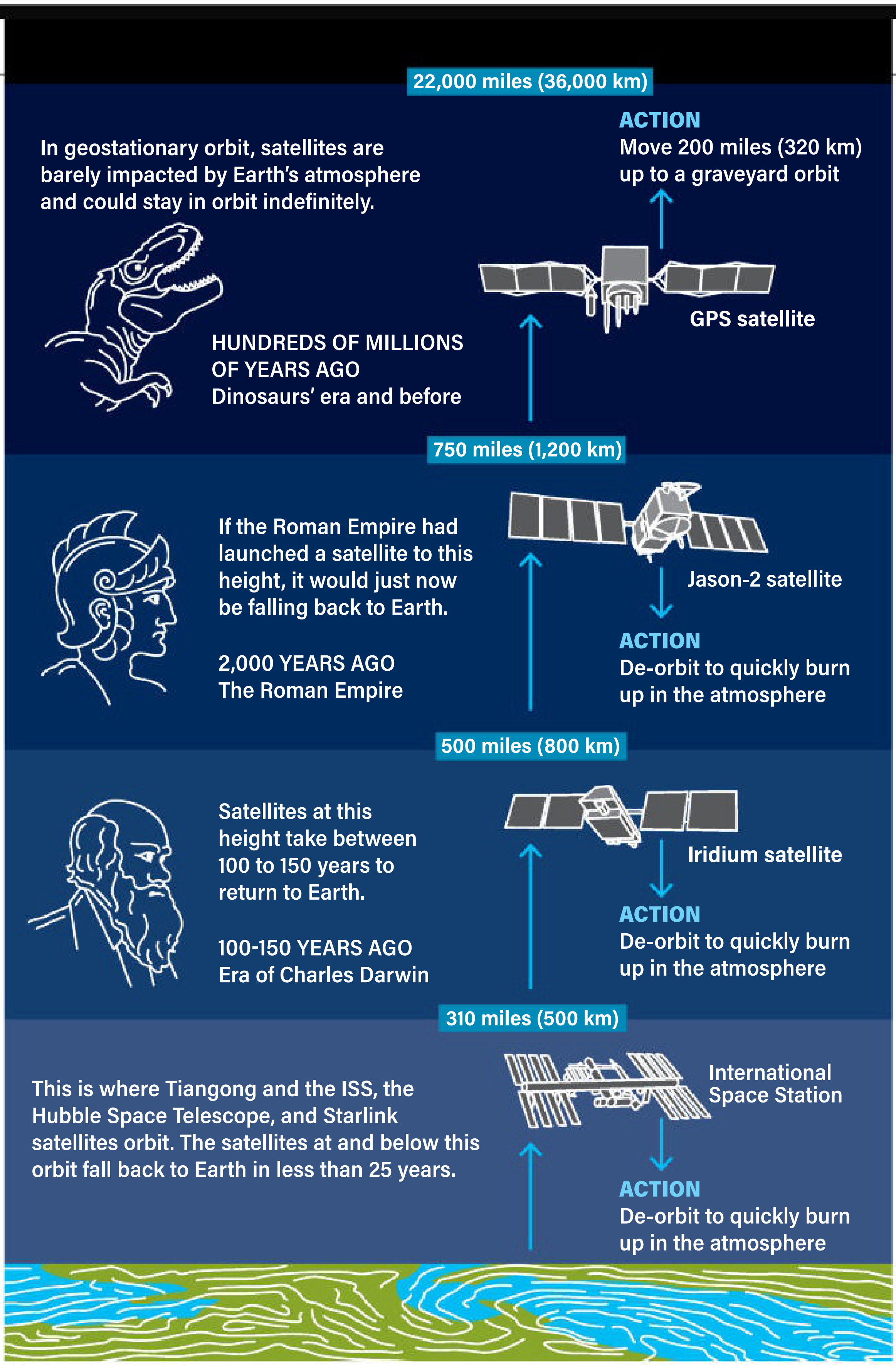
Stellar-mass black holes are formed when a massive star dies. To date, astronomers have only indirectly detected black holes by watching them devour material from a companion star.

But now, researchers think they've found an isolated stellar-mass black hole some 5,200 light-years away. The find has been submitted to *The Astrophysical Journal*.

The team combined two techniques to spot the black hole. The first, microlensing, is a form of gravitational lensing that occurs when a small celestial object crosses in front of a distant star. That object's gravity bends and magnifies the starlight as it travels past. Astronomers can estimate the nearer object's mass by how long the event lasts. A long lensing event caused by something invisible could be a black hole.

But a faint star moving slowly could create the same effect. So, the team also applied astrometry, the precise measurement of objects' positions on the sky. By seeing how much the background star's position appeared to shift during the lensing event, astronomers could better determine the nearer object's mass: just over seven times the mass of the Sun. Such an object would be shining brightly if it was a star. That would mean it must be a black hole.

However, there's another possibility: A separate team's analysis of the same event puts the object between about 1.5 and 4 solar masses, which means it could be a neutron star instead. Astronomers have never detected an isolated neutron star either, so it would still be a remarkable discovery. — ASHLEY BALZER



ASTRONOMY: ROEN KELLY, AFTER ESA/UNOOSA

SATELLITE FALL TIME

Return trip. In February, a solar storm hit 49 of SpaceX's Starlink satellites, destabilizing their orbits enough to send them careening back to Earth. Thankfully, they were small and burned up in Earth's atmosphere, but not every object circling above our heads will simply disappear on its way down. While thus far no one has died from space debris (that we know of), space agencies do have contingency plans. Above we take a look at how long — in comparison to Earth timelines — it would take a satellite at various heights to fall naturally, and the actual plans space agencies have in place, should satellites at specific heights start to fall. — C.B.

FAST FACT

An impact from a debris fragment less than half an inch (1.3 centimeters) wide can generate as much energy as a small car crashing at 25 mph (40 km/h).

Black as night

How do we find true darkness?

Even at night, Earth is enveloped in the soft light of airglow, visible from the International Space Station as an orange-green aura. NASA

It may seem cruel and unusual that days get shorter the moment summer begins. But this expansion of night is ideal for exploring the shadowy topic of darkness.

Actually, the only convenient way to experience full darkness is to lock yourself in a closet. The night certainly isn't black; even in the most rural regions, the heavens aren't truly dark. The source of this illumination is the sky itself.

The name for the sky's natural fluorescence is airglow. It was discovered by Swedish physicist Anders Ångström in 1868, and it's caused by incoming solar particles exciting our atmosphere's gases to produce an effect like constant miniature, widespread aurorae. This background glow varies greatly, but can be up to three times brighter than the combined light of all the stars. That's part of why you can still see where you're going even at night on the darkest country road — as long as you're under the sky, rather than a forest canopy.

So if night is not truly dark, what is? Coal and asphalt only *seem* black compared with more reflective objects viewed in identical conditions. A light meter — remember those? — can confirm that a black cat in sunlight is still 2,000 times whiter and brighter than a white cat under a Full Moon. What's dark in one situation can be light in another.

What's dark in one situation can be light in another.

What about a black hole? Here finally is something that's pitch black under all conditions, as long as you observe it from the outside — an excellent safety precaution. But *inside* these dead suns there'd be plenty of light, since once you pass the event horizon, you'd still see by the light of all the infalling photons around you.

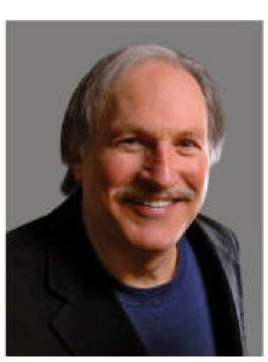
We care so much about blackness that some of us own sky-quality meters, which quantify celestial brightness in magnitudes per square arcsecond. These units also measure surface brightness, whose importance we saw early this year as we struggled to glimpse Comet Leonard. When 5th magnitude, the comet might have seemed to match the Little Dipper's faintest star, visible with the naked eye. But as we know, a star's brightness is concentrated in a point, while a comet has it smeared over a large area, which changes everything.

For you to really see any celestial object, it must be brighter than its background. The glow of a cigarette at the Moon's distance would be a 30th-magnitude dot, technically detectable by the Giant Magellan Telescope. But since the sky is always brighter than that, the job of enforcing lunar no-smoking ordinances would be challenging for Earth-based police, provided they're observing visually.

Human vision has more than a mere darkness-cutoff point. We're equipped with two radically different light-detection systems. Backyard astronomers often use their scotopic mechanism, consisting of some 120 million rod-shaped retinal cells. These are sensitive to low light levels, letting some of us see the Andromeda Galaxy or even the Hercules Globular Cluster from dark backyards without optical aid. But these cells need a few minutes of stimulation to work and are best when dark adapted. They also suffer from colorblindness, unable to observe deep reds. Worst of all, rods deliver only 20/200 resolution. Thus, as pointed out on this page long ago, a galaxy's blurriness comes not from your telescope but your eyesight. Nobody has ever visually seen intricate galactic detail, not even when allowed to peek through the world's largest telescopes.

When a celestial object's brightness exceeds a certain level that varies with wavelength, our eyes switch to their 6 million cone-shaped cells, giving us photopic vision. Now we see in full color and get instant results with 20/20 sharpness. Knowing this explains why stars too dim to show color when viewed with the naked eye, like the Pleiades, burst into their true blue when binoculars ramp up their brightness.

Meanwhile, if you really want to see what black is like — I'll meet you in the closet.



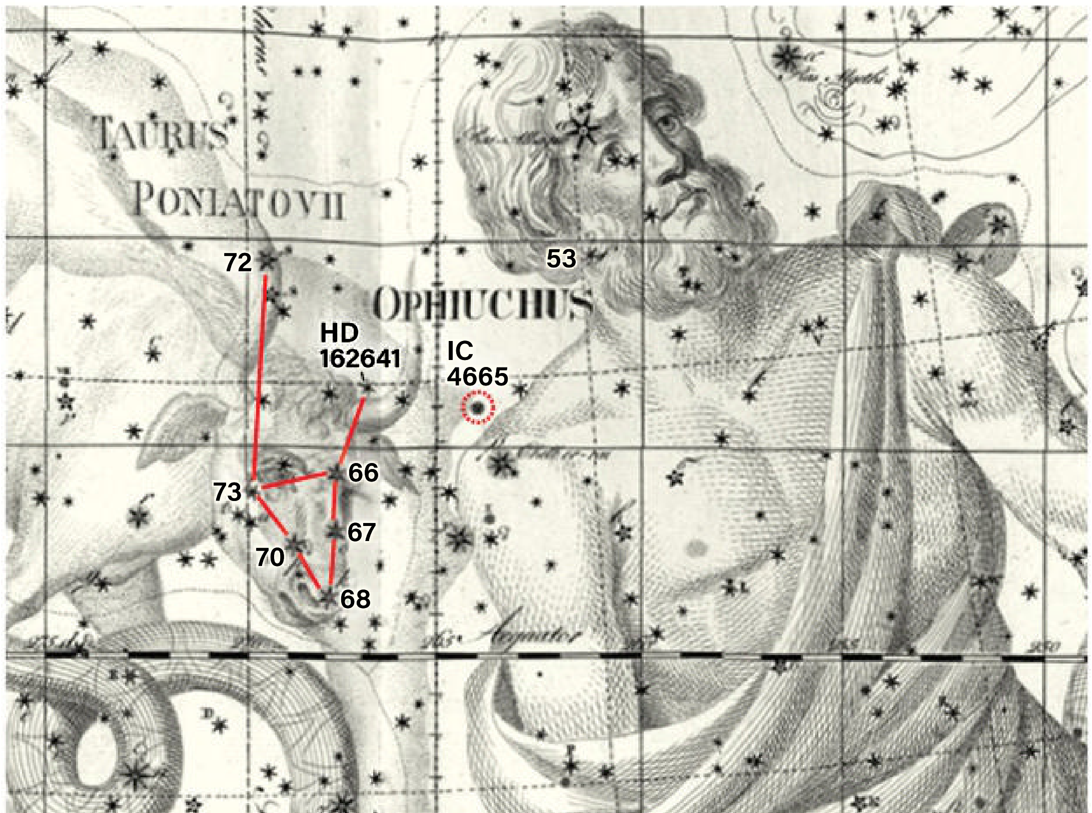
BY BOB BERMAN

Bob's recent book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**

Poniatowski's Bull

Hunt the skies for summer's Taurus.



This annotated version of chart IX within Johann Bode's *Uranographia* shows the position of IC 4665. Unlike Messier or the Herschels, Bode plotted this object — although he failed to label it. IMAGE COURTESY: HISTORY OF SCIENCE COLLECTIONS, UNIVERSITY OF OKLAHOMA LIBRARIES

BY PHIL HARRINGTON
Phil received the Walter Scott Houston Award at Stellafane 2018 for his lifelong work promoting and teaching astronomy.

As most readers know, there are 88 constellations adorning the sky. These were codified in 1930 by the International Astronomical Union through international agreement. Before this, astronomers could create and publicize their own constellations, hoping they would catch on with the masses.

Although many of these obsolete constellations have faded away as footnotes in astronomical history books, there is one lost pattern in the summer sky that is fun to spot through binoculars. You're probably familiar with winter's Taurus the Bull. But what about Taurus Poniatovii?

Taurus Poniatovii, or Poniatowski's Bull, was a small constellation created in 1777 by Marcin Poczobut, a Polish-Lithuanian astronomer and the director of Vilnius Observatory. Poczobut devised the constellation to honor Stanislaus Poniatowski, the king of Poland and Lithuania at the time.

You're probably familiar with winter's Taurus the Bull. But what about Taurus Poniatovii?

Like its namesake constellation in the winter, Taurus Poniatovii is drawn from a V-shaped pattern of stars that fills the field of my 10x50 binoculars. The stars range from 4th to 6th magnitude and can be found just east of Cebalrai (Beta [β] Ophiuchi), the eastern shoulder of Ophiuchus. If you compare the formation to winter's Taurus, then the role of bright-eyed Aldebaran is played by 6th-magnitude 73 Ophiuchi. The tip of the bull's nose is marked by 68 Ophiuchi, while 66 Ophiuchi is the western eye. Fourth-magnitude 72 Ophiuchi marks the end of the eastern horn, while the western horn extends toward 6th-magnitude HD 163641 and beyond. Poczobut drew the bull's body among the faint stars northeast of the V, but he lost me there.

Three of the stars that form the triangular head of Taurus Poniatovii — 67, 68, and 70 Ophiuchi — along with a scattering of about a dozen others belong to a sparse open cluster cataloged as **Melotte 186** (Collinder 359). The group is centered on 67 Ophiuchi and spans 4°. But ironically, its size also makes it difficult to confirm. Which stars in this densely populated area belong to the cluster and which do not is a chore best left to the professionals. A study published in *Astronomy and Astrophysics* in 2006 suggested this may not be a cluster at all, but rather a "moving group" of stars following a similar path through the Milky Way.

That same study mentioned that Melotte 186 might be linked to our next target, **IC 4665**, as both troupes exhibit similar proper motion through the galaxy.

Located some 1,100 light-years away, there is no mistaking the identity of open cluster IC 4665 through binoculars. It can be found just 1° north-northeast of Cebalrai. On dark, clear nights, a faint hint of this cluster is visible to the eye alone. Swing your binoculars its way and IC 4665 resolves into a fine collection of about ten 7th- to 9th-magnitude stars, along with many fainter points. Although its stars are not tightly packed, IC 4665 stands out in binoculars. Depending on how faint you can see, you might see the brighter stars as forming a triangle, a diamond, a short-tailed kite, or even a distorted H.

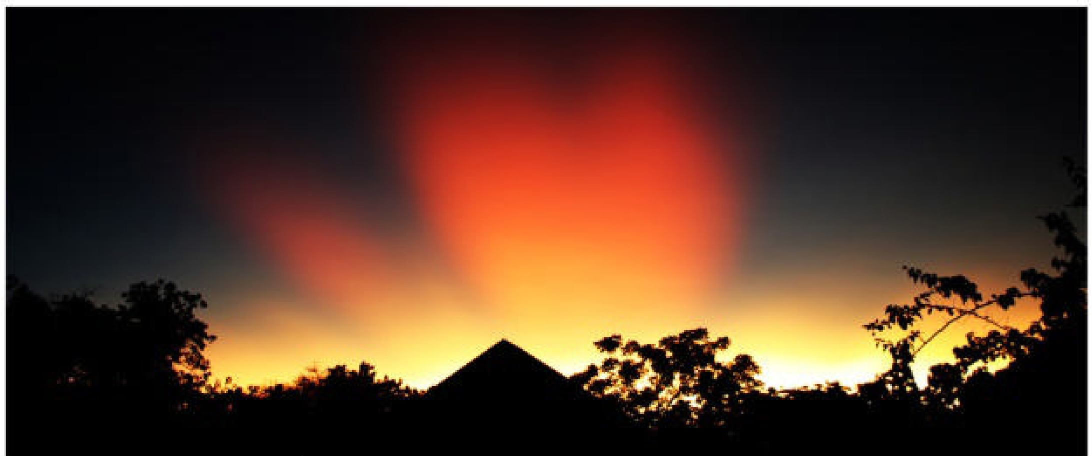
Our last stop this month is the binary star **53 Ophiuchi**. You'll find it 3° south of Rasalhague (Alpha [α] Ophiuchi) at the top of the constellation's pentagonal form. The binary's 6th-magnitude primary star is accompanied by an 8th-magnitude companion, separately cataloged as SAO 122525, about 42" to its south. Both are spectral type A white stars located around 370 light-years away. They are just on the edge of resolution through my 10x binoculars, but should be relatively easy at 12x and up. To resolve the companion, you need to reduce shaking, however. If you don't have image-stabilized binoculars, brace them against something. Better yet, mount them on a tripod.

I welcome observations, suggestions, and comments. Contact me through my website, philharrington.net. Until next month, remember that two eyes are better than one.

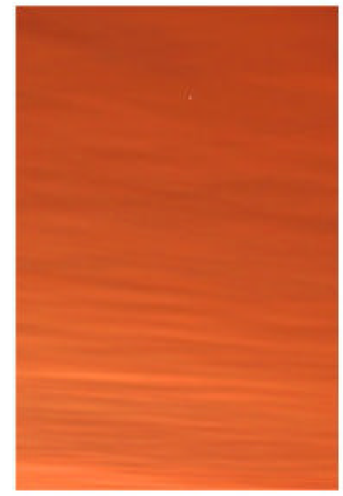
BROWSE THE "BINOCULAR UNIVERSE" ARCHIVE AT **www.Astronomy.com/Harrington**

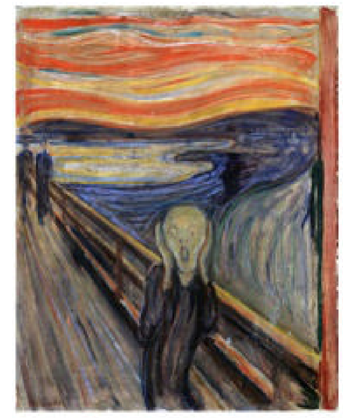
Volcanic twilights

The Tonga eruption early this year yielded an array of atmospheric phenomena.

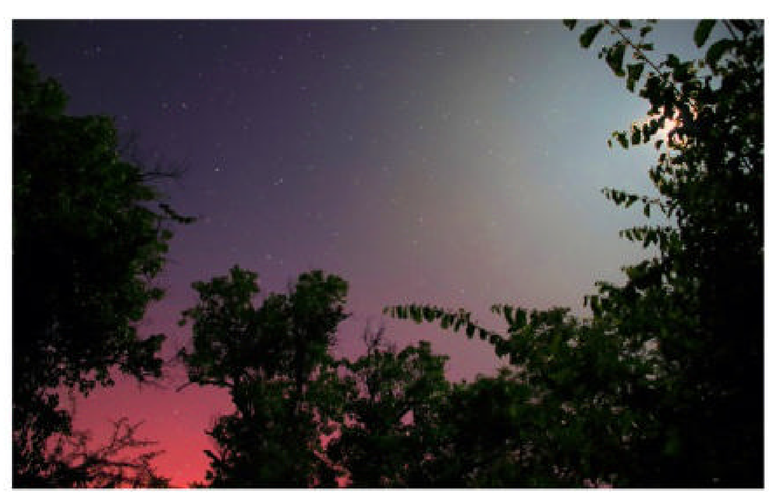


ABOVE: Glowing volcanic aerosols and crepuscular rays formed this display Feb. 8, 2022, over Maun, Botswana. STEPHEN JAMES O'MEARA

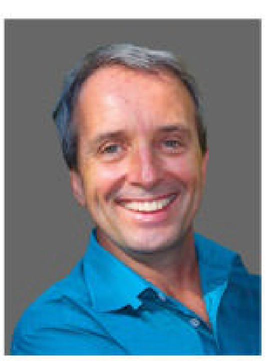




TOP RIGHT: Jupiter shines through volcanic twilight clouds Jan. 23 (top). The sky evokes Edvard Munch's *The Scream* (bottom), which has been linked to volcanic twilights from 1883's Krakatau eruption. STEPHEN JAMES O'MEARA; NATIONAL GALLERY OF NORWAY



BOTTOM RIGHT: Bishop's Ring as seen shortly before night Feb. 8, centered on a near First Quarter Moon. A volcanic glow lingers in the west. STEPHEN JAMES O'MEARA



BY STEPHEN JAMES O'MEARA

Stephen is a globe-trotting observer who is always looking for the next great celestial event.

The powerful Jan. 15, 2022, eruption of the Hunga Tonga-Hunga Ha'apai volcano in the South Pacific archipelago nation of Tonga produced plumes that reached an altitude of 36 miles (58 kilometers). The plume contained 400,000 tons of sulfur dioxide, which drifted west with the stratospheric winds — and soon began to produce remarkable sunsets in the Southern Hemisphere. Stunning images appeared in the news as the cloud swept west over Australia.

Five days later, the cloud passed over southern Africa, including my home in Maun, Botswana. It arrived as a high-altitude haze blanketing the Sun, which shone as if seen through frosted glass. Closer inspection of the haze revealed it was composed of irregularly spaced ripple clouds, giving the sky a crinoline texture. Contrast between the clouds and sky intensified around the time of sunset, when they underwent magnificent color changes, morphing from silvery blue to tangerine infused with lemon to a velvety scarlet reminiscent of Edvard Munch's *The Scream*. As the Sun set, the clouds in the west appeared so optically thick that I couldn't imagine starlight penetrating them. But come twilight, the stars and planets burned through them seemingly unimpeded.

Over the next three days, the rippled sky put on phenomenal shows of light, color, texture, and tone. Even after the official start of night, volcanic glow and ruffled clouds remained visible to the unaided eye close to the western horizon for several minutes.

The rippled sky put on phenomenal shows of light, color, texture, and tone.

Bishop's Ring

The rarest of the phenomena was the occurrence of Bishop's Ring — an enormous single-ringed aureole of light centered on the Sun or Moon. Typically, a solar or lunar aureole — formed by the diffraction of light by water droplets in clouds — has a radius ranging from 0.4° to several degrees, depending on droplet size. The radius of Bishop's Ring, however, usually consists of a roughly 20° silvery blue interior surrounded by a diffuse, smoky orange outer ring (adding an additional 10° to 20° or more to the Ring's radius, depending on particle size).

Sereno Edwards Bishop of Honolulu first recorded the phenomenon in the aftermath of the 1883 eruption of Indonesia's Krakatau volcano. More than a century later, following the 1991 eruption of Mount Pinatubo in the Philippines, lidar studies of Bishop's Ring found that this diffraction phenomenon was caused by frozen sulfuric acid particles with a radius of about 0.8 microns.

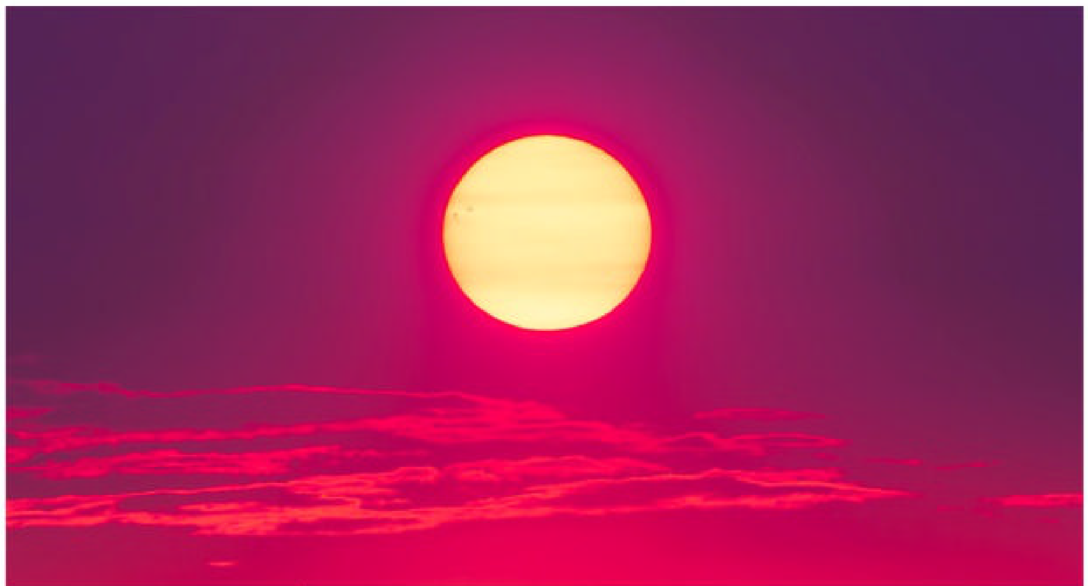
The Tongan volcanic clouds vanished after Jan. 25, — only to return 10 days later, creating further stunning displays (although the rippling effect was diminished). February's waxing Moon also allowed me to measure Bishop's Ring visually and photographically. Interestingly, the radius of the ring near First Quarter Moon was only about half the radius near Full Moon, a 10° inner aureole versus a 20° inner aureole. In both cases, the outer aureole essentially matched the size of the inner aureole.

It is unclear how long the atmospheric effects will linger or how widespread across the globe they will be. As always, send any observations you have made of these phenomena to sjomeara31@gmail.com.

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara**

Safely observe the Sun

Your eyes are worth protecting.



Seen through a hazy sky at sunset, the Sun in this two-exposure shot features a large group of sunspots on its eastern limb. The image was taken with a 2.6-inch refractor and a Canon 60Da June 30, 2014. ALAN DYER

"Danger ahead!" You don't usually associate this warning with a hobby as seemingly innocuous as backyard astronomy. Still, there is an inherent risk to life and limb any time you drive to and from a remote observing site or skygaze alone in an unfamiliar environment. Observers in desert areas must worry about venomous snakes and scorpions. And in humid climates, a mosquito or tick bite can lead to a potentially fatal disease. Frigid wintry weather also brings its own hazards, like slippery ice and frostbite.

However, perhaps the most dangerous astronomical undertaking — at least to the eye — is solar observing. I avoided this activity during my early years as an amateur astronomer. But in the summer of 1971, I acquired a 60mm f/11 refracting telescope. Among its accessories was a solar filter that screwed into the eyepiece. At last, the Sun was mine to explore! The filter produced a "white light" image of the Sun, revealing activity on its surface, or photosphere. I remember the excitement of seeing sunspots for the first time. Day after sunny day, I watched, spellbound, as they seemingly appeared from nowhere before eventually fading back into oblivion, all the while drifting across the face of our life-sustaining star.

Several years passed before I learned that the glass in screw-in solar filters has a nasty habit of shattering due to excessive heat. Had this happened while I was peering into my scope's eyepiece, a sudden blinding flash of unfiltered and concentrated sunlight could have caused permanent eye damage. I thank my lucky stars that never happened.

Fortunately, I also learned that I could still see the Sun with my little refractor by employing a simple technique called solar projection. All I had to do was aim my scope at the Sun, not with the finderscope, which should be capped or entirely removed, but using the scope's shadow as a guide. I would adjust the telescope tube to make its shadow on the ground as small as possible. And once the telescope was on target, the eyepiece would light up with sunlight. I then held a piece of white cardboard about a foot away from the eyepiece and adjusted the focus until the bright circle of light (the Sun's projected image) was sharp at the edges. Once again, I could follow the antics of sunspots — maybe not as clearly as I could with direct viewing, but at least with minimal risk to my eyes.

During those early years of solar observing, I learned that my little refractor is an ideal telescope for projecting the Sun's image. Lacking secondary mirrors, refracting telescopes are less likely to suffer internal heat damage than reflectors or catadioptrics. My scope's modest 2.4-inch aperture also captures less sunlight (and therefore heat) than a larger telescope. The 20mm Huygenian eyepiece that came with it yielded a magnification of 35x, ample for a celestial body that's a half-degree across. Moreover, the simple Huygenian design, scorned by serious amateur astronomers, is perfect for solar projection because it consists of two separated lenses. Concentrated solar heat can "cook" a more complex (and expensive) eyepiece composed of one or more cemented lenses.

Projecting the Sun's image onto cardboard may have been a sensible alternative to risking permanent blindness, yet I still yearned to view the Sun directly and safely. For that reason, I invested in a full-aperture mylar solar filter that would fit my refractor. Unlike a screw-in solar filter, an aperture solar filter is affixed to the front of the telescope tube, filtering out sunlight before it enters the scope. Whether comprised of mylar, glass, or polymer film, this setup offers views of the Sun's photosphere without the risk of shattering solar filters or cooking eyepieces. With proper equipment and a few simple techniques, at last, the Sun was *truly* mine to safely explore!

With proper equipment and a few simple techniques, at last, the Sun was *truly* mine to safely explore!

Now it's your turn to own the Sun. Be it by projecting its image with a small refractor or by viewing it directly with a larger scope fitted with an aperture filter, the Sun can be a safe, satisfying target for backyard astronomers. Just watch out for rattlesnakes, mosquitos, and other drivers!

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: the answer to all your backyard astronomy questions. Clear skies!

BY GLENN CHAPLE

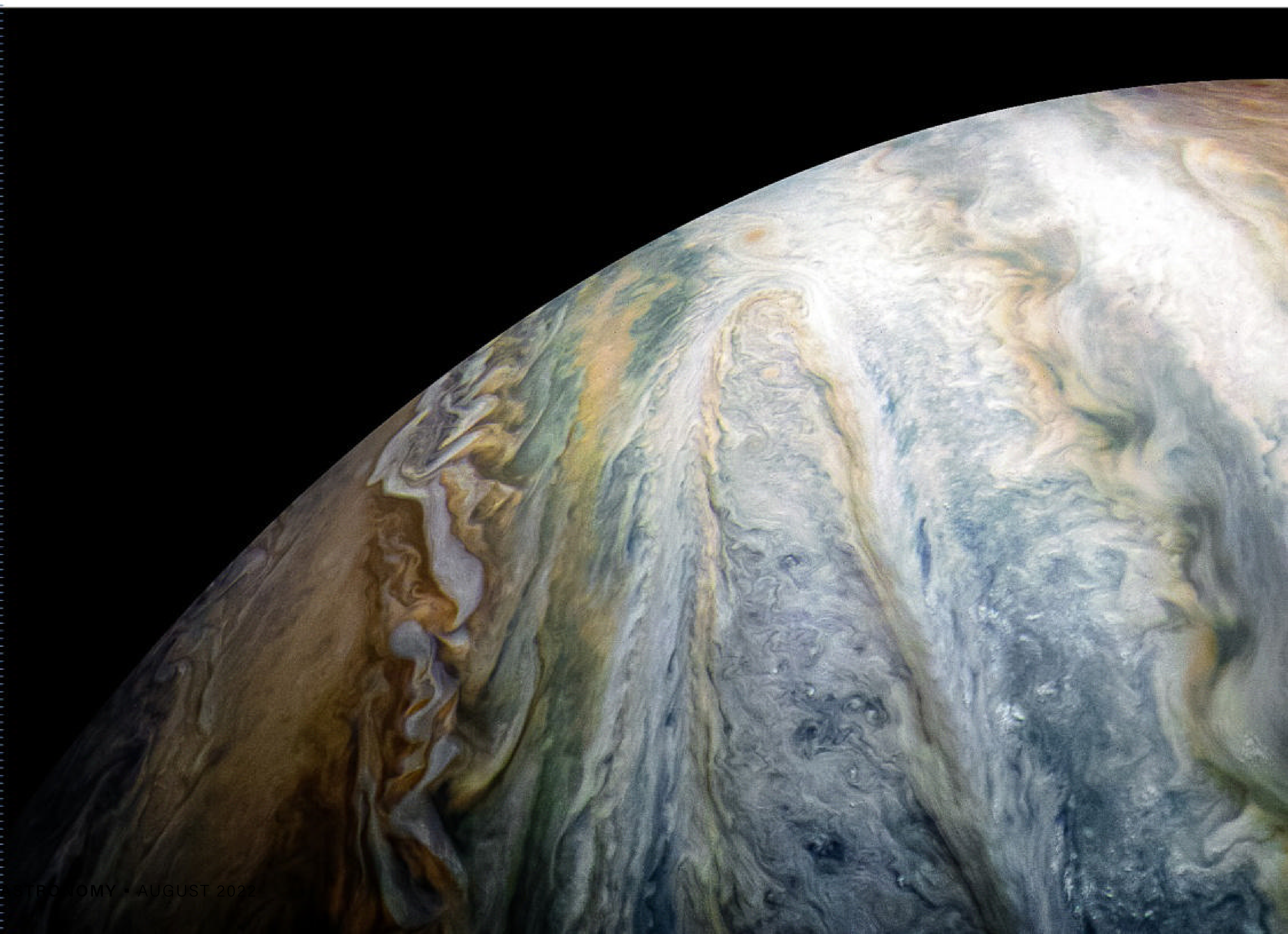
Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple**

How JUNO

NASA's plucky probe has brought us unprecedented views of the solar system's biggest planet, from its enigmatic aurorae to its dramatic storms. **BY BEN EVANS**

WHENEVER JUPITER, thunderbolt-wielding lord of the gods in ancient Roman myth, misbehaved with the ladies, there was one person he most feared: his long-suffering yet ferocious wife, the goddess Juno. It was said that Jupiter conjured fog to hide his illicit

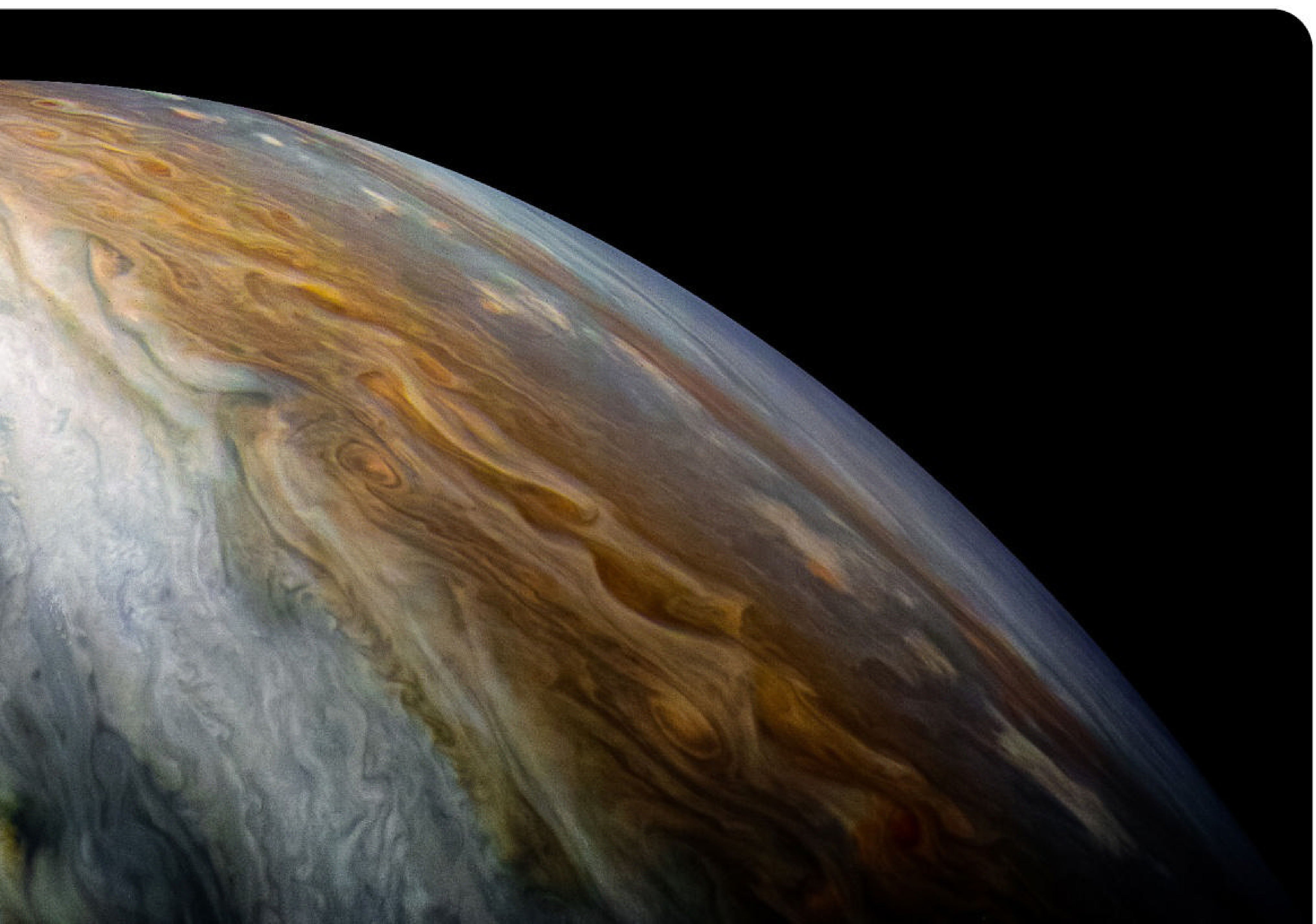


unmasked JUPITER

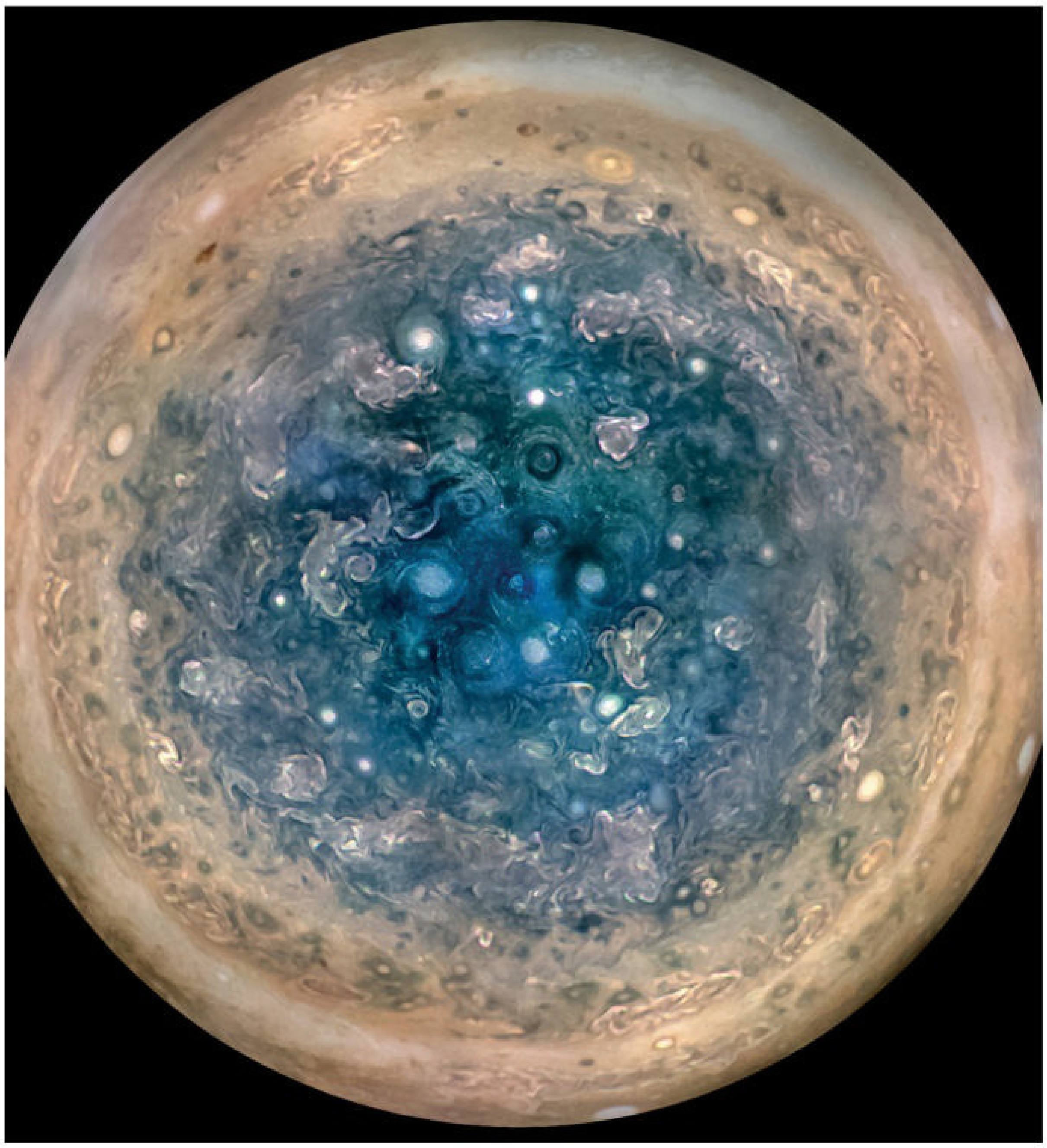
liaisons from his wife. But Juno always saw through her faithless husband's philandering to reveal his every misdeed.

Like its mythical namesake, the planet Jupiter guards its secrets with jealous pride, its bulk swaddled in thick clouds. For the last six years, though, a spacecraft bearing Juno's name has watched Jupiter from orbit, stripping away its secrets and furnishing new insights into its interior and evolution.

This robotic Juno has answered many longstanding questions and uncovered new riddles to challenge us. Its onboard camera, JunoCam, has turned Jupiter from a planet into an objet d'art, capturing spectacular planetscapes with sprawling storms. And the craft's scientific toolkit has made it as much a force to be

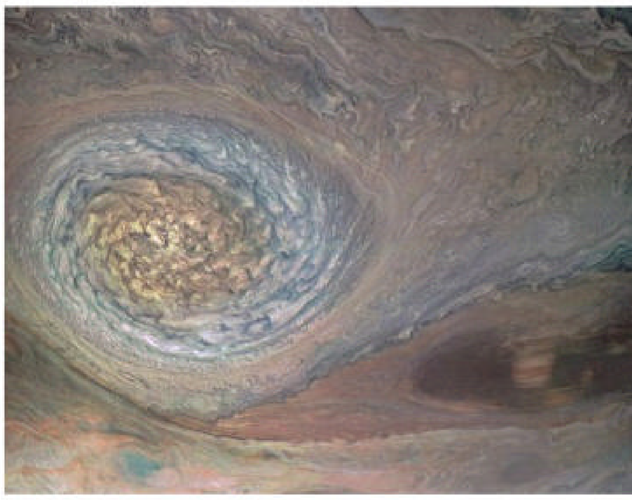


Incredible bulk// Cloud belts swirl around Jupiter's southern hemisphere in this image captured by Juno at an altitude of 8,453 miles (13,604 km) on Dec. 16, 2017. ENHANCED IMAGE BY KEVIN M. GILL (CC-BY) BASED ON IMAGES PROVIDED COURTESY OF NASA/JPL-CALTECH/SWRI/MSSS



LEFT: **New view//** Blue cyclones encircle Jupiter's south pole in this enhanced color image. NASA/JPL-CALTECH/SWRI/MSSS/BETSY ASHER HALL/GERVASIO ROBLE

BELOW: **Red marble//** Broad belts and swirling storms — including Jupiter's Great Red Spot — are visible in this image taken by JunoCam Feb. 12, 2019. ENHANCED IMAGE BY KEVIN M. GILL (CC-BY) BASED ON IMAGES PROVIDED COURTESY OF NASA/JPL-CALTECH/SWRI/MSSS



North by north// The North North Temperate Zone Little Red Spot is about half the size of Jupiter's Great Red Spot, but still measures roughly 5,000 miles (8,000 km) across. NASA, JPL-CALTECH, SWRI, MSSS, PROCESSING: GERALD EICHSTADT, DAMIAN PEACH

reckoned with as the goddess herself.

Flying by Jove

The largest and most massive planet in the solar system, Jupiter has been observed since antiquity. But before the invention of the telescope, we knew little of its nature, including its four large Galilean moons (named for their discoverer, the Italian polymath Galileo Galilei) and its most striking atmospheric feature, the roiling Great Red Spot. Our knowledge has multiplied since the dawn of the Space Age, thanks to NASA's Pioneer, Voyager, and Galileo probes, which surveyed the giant planet between 1973 and 2003.

Juno is the most advanced spacecraft yet to visit Jupiter, brimming with nine science instruments, including infrared and ultraviolet sensors, a radiometer and magnetometer, and energetic particle detectors. For power, it relies on arrays of solar panels — a first for a spacecraft at Jupiter, where sunlight is about 4 percent as strong as at Earth. With its windmill-like trio of 29-foot-long (9 meters) solar arrays fully unfurled, the probe spans about the same area as a basketball court. All previous craft that had voyaged that deep into the solar system relied on nuclear generators. But a worldwide shortage of plutonium-238 nuclear fuel coupled with advances in solar-cell technology made it both necessary and possible for Juno to utilize the Sun's energy to power itself.

Launched on an Atlas V rocket from Cape Canaveral Aug. 5, 2011, Juno voyaged 1.74 billion miles (2.8 billion kilometers) to reach Jupiter. Its convoluted 59-month trek carried it initially beyond the orbit of Mars, but a pair of maneuvers in August and September 2012 redirected it back past Earth for a gravitational slingshot maneuver in October 2013. This yielded an 8,800-mph (14,000 km/h) speed boost. On

July 4, 2016, as Juno hurtled toward its target, a Jupiter Orbit Insertion (JOI) engine burn reduced its speed by 1,200 mph (1,950 km/h), allowing the probe to thread a fine needle between the planet and its radiation belts.

Juno then entered an elliptical orbit not around Jupiter's equator, but looping from pole to pole. This has given scientists a perspective on Jupiter never seen by the Pioneer and Voyager probes, which made flybys of the jovian system in the 1970s, and even the Galileo mission, which girdled the planet in an equator-hugging orbit from 1995 to 2003.

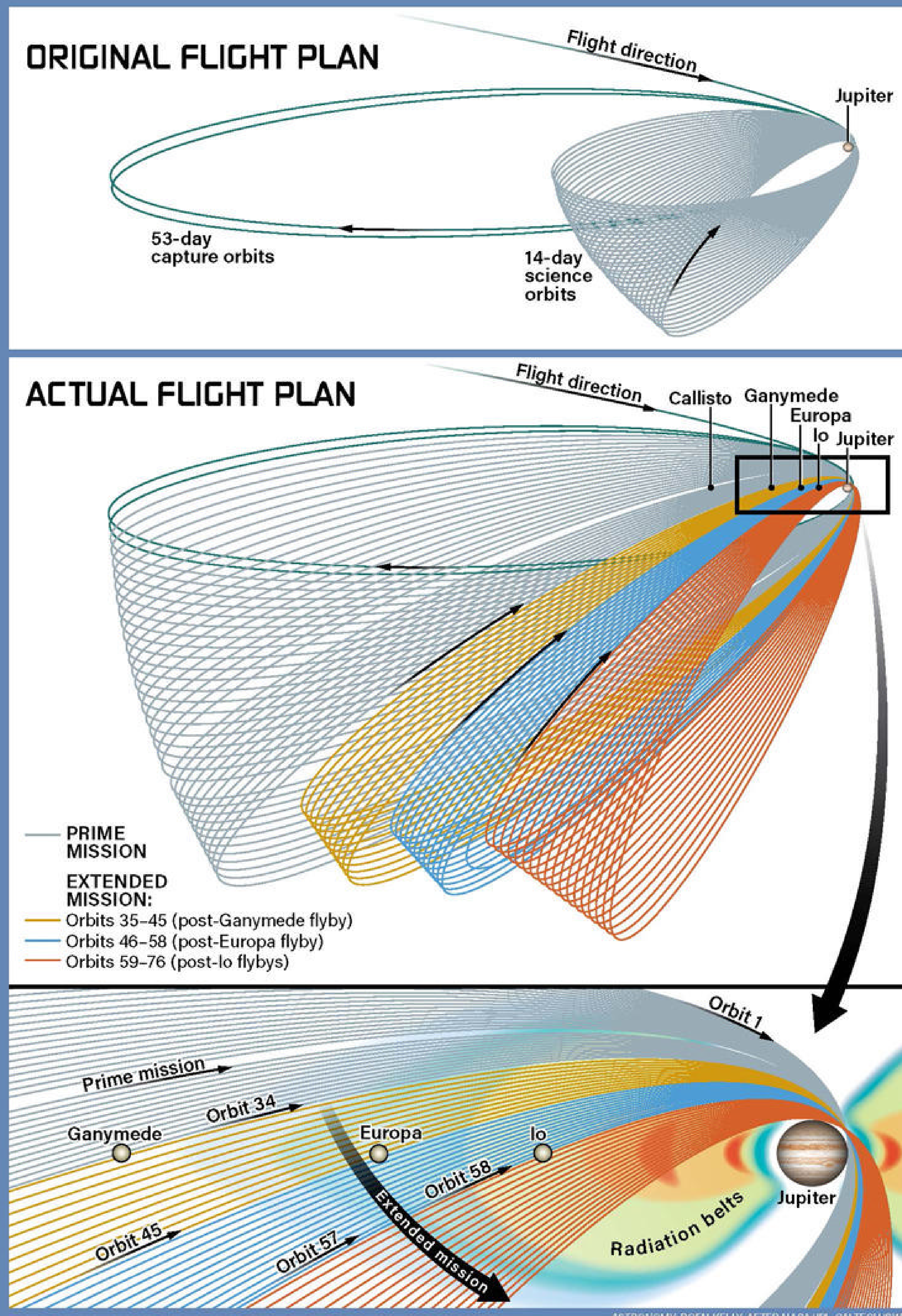
From this unique vantage point, Juno made the first observations of the planet's extreme northerly and southerly latitudes. It has also flown more than 10 times closer to its rollicking clouds, raging tempests, and savage radiation belts than any previous mission. In unmasking this multi-hued megaworld, Juno would have made its pansophical namesake proud.

Juno's initial orbit lasted 53 days, giving engineers time to prepare to test the craft's instruments during a close passage to Jupiter that August. Then, in October 2016, Juno's flight plan called for a Period Reduction Maneuver (PRM) to bring Juno in a tighter, 14-day orbit.

Circling Jupiter every two weeks, Juno was expected to have an operational life of just 20 months. The main reason was the intense radiation belts at Jupiter, which had almost cooked the circuits of the earlier Pioneer probes. During their brief flybys, they sustained 1,000 times the human-lethal dose of radiation. NASA expected that Juno would endure the equivalent of over 100 million dental X-rays over its lifetime.

To guard against the onslaught of charged particles

PLOTTING A COURSE



ASTRONOMY: ROEN KELLY, AFTER NASA/JPL-CALTECH/SWRI

JUNO'S APPROACH TRAJECTORY was carefully planned to put the craft into a 53-day polar orbit that avoided Jupiter's radiation belts and kept its solar panels constantly exposed to sunlight. The original mission plan (top) then called for Juno to tighten its orbit to a 14-day loop that would precess over time, slowly increasing its exposure to the radiation belts. When the mission team decided to cancel that maneuver due to a malfunctioning fuel valve, Juno remained in its 53-day orbit for the duration of its prime mission (middle).

In July 2021, Juno began its extended mission (detailed at bottom) shortly after making a close pass of Ganymede, which reduced the spacecraft's orbital period from 53 to 43 days. A planned flyby of Europa in September 2022 will further shorten the orbit to 38 days. And two flybys of Io, in December 2023 and February 2024, will trim it to 33 days. The extended mission is approved to last until September 2025.

Cyclone close-up// Juno made the closest-ever approach to Jupiter's Great Red Spot on July 11, 2017, taking this shot from just 6,100 miles (9,900 km) above the cloudtops. NASA/SWRI/MSSS/GERALD EICHSTÄDT/SEÁN DORAN

funneled by Jupiter's magnetic field, Juno's electronics were made with radiation-resistant tantalum, its wiring was wrapped in copper and stainless steel braiding, and its computers were shielded behind the 0.4-inch-thick (1 centimeter) walls of a 500-pound (200 kilograms) titanium vault. "Juno is basically an armored tank going to Jupiter," said the mission's principal investigator Scott Bolton of the Southwest Research Institute in a 2010 statement. "Without its protective shield, or radiation vault, Juno's brain would get fried on the very first pass near Jupiter."

A flexible flight plan

On Aug. 27, 2016, Juno experienced its first close approach of Jupiter, or perijove, sweeping just 2,600 miles (4,200 km) above Jupiter's clouds, closer than any spacecraft in history. This flyby provided our first ever high-latitude glimpse of the north pole. It took almost two days to download the 6 megabytes of data from perijove 1, but the results proved well worth the wait. "It's bluer in color up there than other parts of the planet, and there are a lot of storms," noted Bolton. "There is no sign of the latitudinal bands or zones and belts that we are used to — this image is hardly recognizable as Jupiter."

Juno revealed the poles are dominated by densely packed cyclones, all jostling for position. In the north resides a central cyclone, encircled by eight others, all around 2,000 miles (3,200 km) in diameter, as wide as the contiguous U.S. Clinging to the periphery of the pole, as if itching for admission, are other tumultuous weather systems, including a 5,000-mile-wide (8,000 km) behemoth known as the North North Temperate Little Red Spot 1, the third-largest anticyclonic oval storm on Jupiter.

The planet's deep south proved no less tempestuous, harboring a pentagon of five cyclones around a central sixth. But while the northern storms remained stable over time, scientists were astonished in November 2019 when another cyclone — smaller than the rest, yet still the size of Texas — muscled its way into the southern group. The gatecrasher's petulance did not go unpunished and within months, it had been pushed out and vanished. To Bolton, "it almost appeared like the polar cyclones were part of a private club that seemed to resist new members."

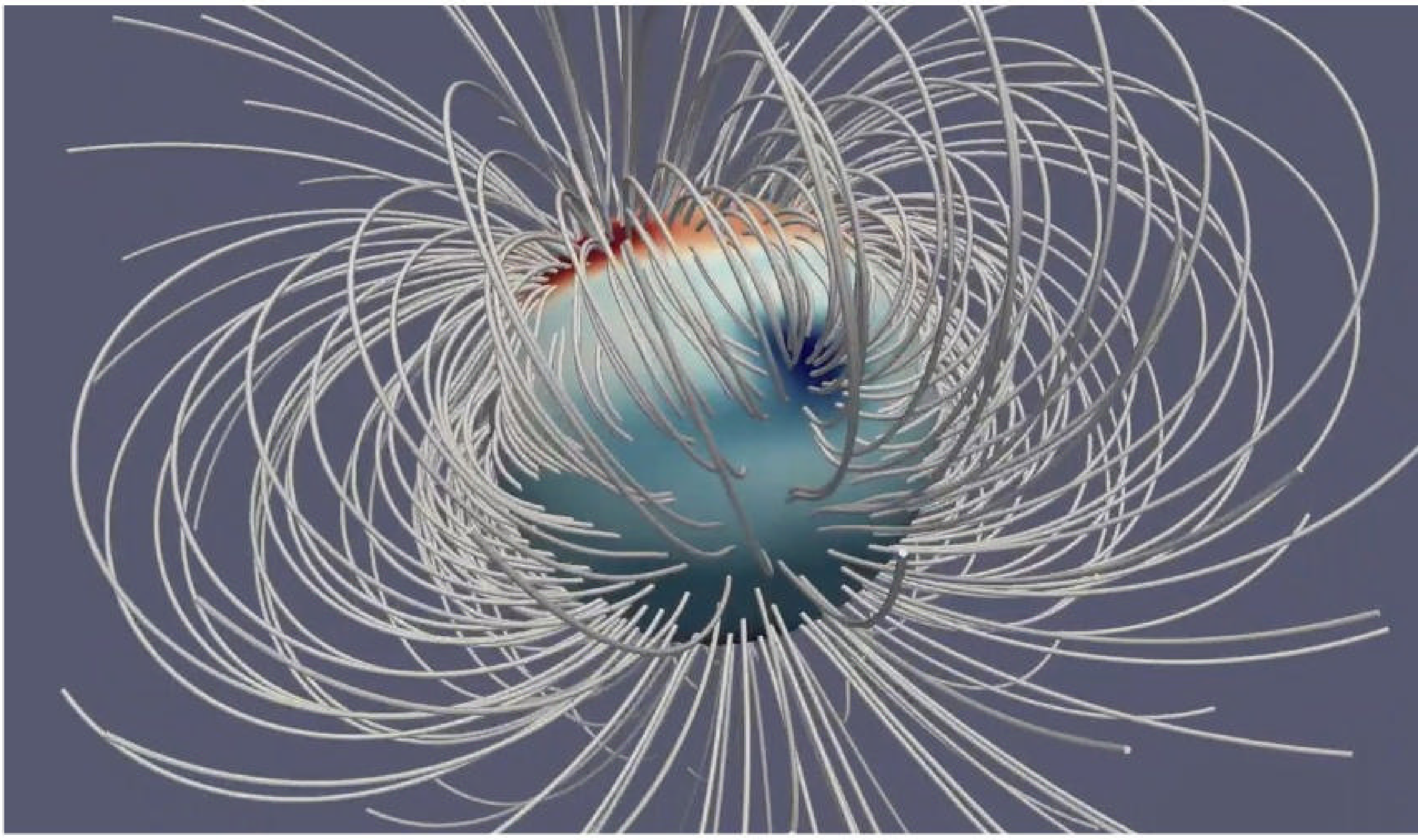
As well as spotlighting the storminess of the poles, Juno's first perijove showed the planet's magnetic fields and aurorae are much more powerful and extensive than previously thought. It revealed the field is irregularly shaped, lumpy in places, and — at 7.766 Gauss — more than 10 times as powerful as Earth's magnetic field at its strongest.

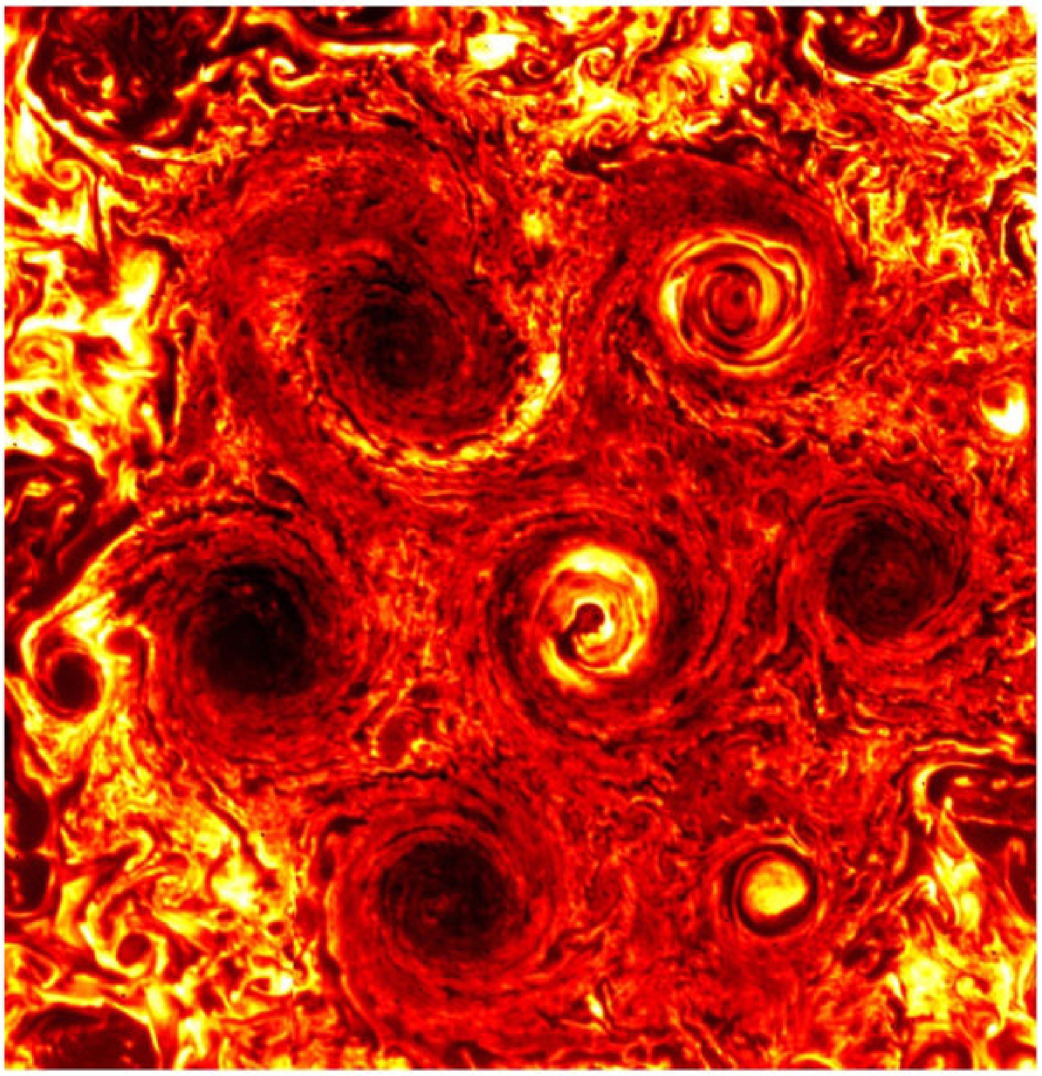
But despite a promising start, all was not well. The PRM burn in October 2016 was postponed due to worries about helium valves in the main engine's pressurization system. Although the valves opened on command, they did so more sluggishly than expected. Matters were compounded further when an unrelated computer reboot threw Juno into safe mode for a few days in late October.

The most efficient time to perform the PRM was during the risky perijove passage, but an increasingly nervous NASA chose to weigh its options before trying again. "There was concern that another engine burn could result in a less-than-desirable orbit," said Project Manager Rick Nybakken of the Jet Propulsion Laboratory in a statement. "The bottom line is a burn represented a risk to completion of Juno's science objectives."

This risk ultimately decided the issue. In February 2017, NASA announced that Juno

Dawn storms// The polar aurorae of Jupiter can suddenly intensify at morning in so-called dawn storms, which bear a resemblance to auroral storms on Earth. This image is a composite of visible light and ultraviolet data from Juno. NASA/JPL-CALTECH/SWRI/UVS/STSCI/MODIS/WIC/IMAGE/ULIÈGE





ABOVE: **Great Blue Spot//** This frame from a simulation of Jupiter's magnetic field shows the Great Blue Spot, an invisible region where the field is particularly strong with negative polarity. NASA/JPL-CALTECH/HARVARD/MOORE ET AL.

LEFT: **Newcomer//** On Nov. 4, 2019, Juno saw a brand-new, Texas-sized cyclone (lower right) join the six existing storms gyrating around Jupiter's south pole. NASA/JPL-CALTECH/SWRI/ASI/INAF/JIRAM

would remain in its 53-day orbit for the rest of the mission. Researchers did not expect the longer orbit to impair the science, as the probe's altitude during each perijove would remain the same as it would have during its planned 14-day orbit. Indeed, the 53-day orbit meant that Juno would actually spend less time in the regions of most intensive radiation. "This is significant," said Bolton, "because radiation has been the main life-limiting factor for Juno."

Massively magnetic

A bonus of the 53-day orbit was the ability to spend more time in the poorly understood fringes of Jupiter's magnetic field. Jupiter's internal magnetism carves a vast cavity into the solar wind, a magnetic realm of influence with a field thousands of times stronger than Earth's. Researchers inferred its existence with ground-based radio and microwave observations in the 1950s. The Pioneer missions flew through it and the Ulysses probe found that Jupiter's region of magnetic influence — or magnetosphere — extends about 5 million miles (8 million km) toward the Sun. And the Voyagers showed that the solar wind splays Jupiter's magnetic field back beyond the planet, forming a magnetotail that extends 460 million miles (750 million km), almost out to Saturn's orbit.

Later missions also visited Jupiter: In addition to Galileo's extended stay, Ulysses passed through the planet's polar magnetosphere during a 1992 flyby and New Horizons traversed 100 million miles (160 million km) along its magnetotail in 2007

while en route to Pluto and the Kuiper Belt. But these were brief encounters. It was left to Juno to undertake the first global mapping campaign.

Mapping the magnetosphere tells us more than just its extent. It's also one of the few ways to understand Jupiter's gaseous interior, including its magnetism and core. The planet's enormous gravity compresses its atmosphere so tightly that it is virtually impenetrable to remote-sensing tools.

Scientists think that beneath Jupiter's outermost layers of molecular hydrogen resides an electrically conducting shell of liquid metallic hydrogen. The existence of this exotic substance at Jupiter was first proposed in 1951. It has long been thought to play a key role in generating Jupiter's magnetic field, its rotation acting as a dynamo.

However, the magnetic field's lumpiness that Juno observed suggested that the field might be created by dynamo effects closer to the planet's visible surface, above the liquid metallic hydrogen boundary. In May 2019, Juno showed the field changes over time — a phenomenon called secular variation — and its effects are particularly prominent near an anomalous area of magnetism near the equator. As the spot appears blue in maps produced with Juno data, scientists have dubbed it the Great Blue Spot.

Jupiter's magnetic field is also capable of creating powerful aurorae many times more energetic than Earth's own.

Jupiter's magnetic field is also capable of creating powerful aurorae many times more energetic than Earth's own. The Voyagers witnessed polar displays spanning 18,000 miles (29,000 km) that were accompanied by whistling radio emissions. Analysis revealed these phenomena were partly triggered by material flowing along magnetic field lines from Jupiter's volcanic moon, Io.

Juno's time in Jupiter's outer magnetosphere yielded an array of discoveries. In September 2017, researchers reported that Juno had found auroral electrons pouring into the atmosphere at energies approaching 400,000 electron volts, 10 times stronger than their counterparts on Earth. Yet, unlike at Earth, they don't appear to be responsible for the strongest aurorae at Jupiter. This suggests that jovian lights are induced by a form of turbulence in the magnetic field that accelerates charged particles.

More recently, Juno returned the first observations capturing the full birth and evolution of "dawn storms" — intense, short-lived events that regularly appear at sunrise, where the main auroral ovals that circle the planet's poles broaden and brighten. Juno has also derived insights into Jupiter's enigmatic X-ray-emitting aurorae and how they may heat the wider atmosphere. And in April 2021, Juno's ultraviolet spectrograph linked auroral

Jupiter blues// A blue-hued cloud system whirls across Jupiter's northern hemisphere in this image taken by JunoCam Oct. 24, 2017, at an altitude of just 11,747 miles (18,906 km) — roughly the distance from New York City to Perth, Australia. NASA/JPL-CALTECH/SWRI/MSSS/GERALD EICHSTADT/SEAN DORAN, CC NC SA

JUNOCAM'S VISUAL IMPACT

ALTHOUGH ALL OF JUNO'S NINE INSTRUMENTS have aided the probe's scientific harvest, it is JunoCam's spectacular imagery of Jupiter's swirling surface that has truly resonated in the wider world. The only visible light camera on the spacecraft, JunoCam was conceived not as a scientific instrument, but as a tool for public outreach — and it has been wildly successful.

Members of the public have taken Juno's raw imagery and reworked it to present different artistic interpretations of Jupiter. One rendition uses two glaring oval storms to create a pair of eyes, which Jason Major called Jovey McJupiterFace (top). Mik Petter used mathematical fractals to recreate Jupiter almost like a petri dish, teeming with organisms (middle). And Rita Najm enhanced the color and contrast of one image to make a beautiful portrait of Jupiter's clouds, wrapped around each other like the petals of roses (bottom).

TOP TO BOTTOM: ENHANCED IMAGE BY JASON MAJOR BASED ON IMAGES PROVIDED COURTESY OF NASA/JPL-CALTECH/SWRI/MSSS; ENHANCED IMAGE BY MIK PETTER (CC-NC-SA) BASED ON IMAGES PROVIDED COURTESY OF NASA/JPL-CALTECH/SWRI/MSSS; IMAGE DATA: NASA/JPL-CALTECH/SWRI/MSSS, IMAGE PROCESSING: RITA NAJM CC BY

activity on Jupiter for the first time with charged particles at the boundary region between the magnetosphere and the solar wind.

Stormy weather

Juno has also been a prolific storm-chaser, adept at tracking Jupiter's wild weather. The craft has seen series of Earth-sized cyclones lined up like strings of pearls, and in December 2019, serendipitously witnessed a pair of storms colliding. It watched Jupiter's second-biggest storm, Oval BA — the result of three spots that merged in 2000 — change color from deep red to almost white in 2015 and 2016. It measured vigorous winds that extend 1,800 miles (2,900 km) deep and shear apart electrically-conducting material in the jovian interior, altering the shape of the planet's magnetic field. And in 2020, Juno began tracking a small storm found by South African astronomer Clyde Foster, now called Clyde's Spot.

But of all Jupiter's storms, none is bigger or longer lasting than the famous Great Red Spot. Continuously observed since the 19th century, it may even be the same storm found by the English scientist Robert Hooke in 1664. The counterclockwise-rotating spot now measures 10,000 miles (16,000 km) in diameter, having noticeably shrunk in recent years. It has also shown dramatic variations in color, morphing from brick-red to its present salmon-pink. In July 2017, Juno flew directly over the spot at a height of just 5,600 miles (9,000 km), spying a tangle of dark, veinous clouds weaving through it.

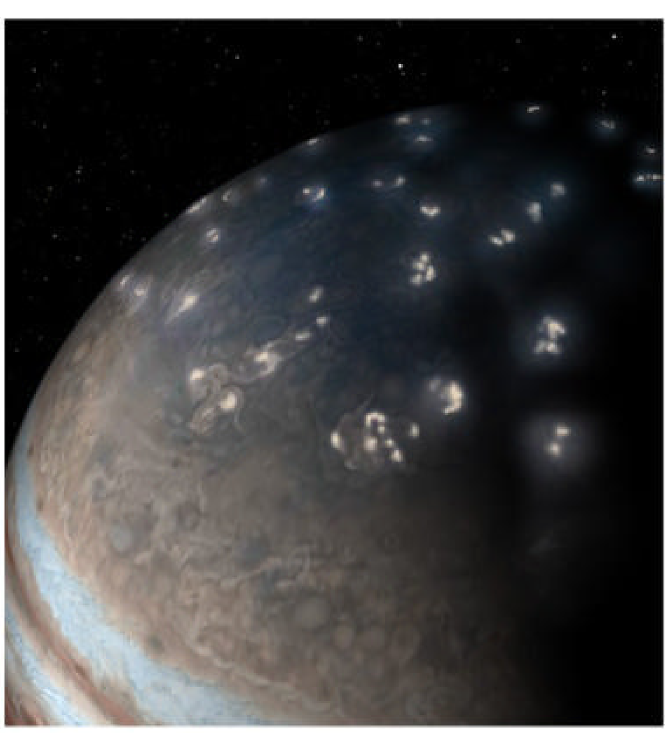
Pearly whites// The series of white storms called the String of Pearls is visible near the limb of Jupiter in this image taken Dec. 16, 2017. NASA/SWRI/MSSS/GERALD EICHSTÄDT/SEÁN DORAN

The probe's microwave radiometer showed the spot extends further into the atmosphere than its neighboring clouds, penetrating at least 200 miles (320 km) deep. "The Great Red Spot's roots go 50 to 100 times deeper than Earth's oceans and are warmer at the base than they are at the top," said Andrew Ingersoll, a planetary scientist at Caltech, in a statement. "Winds are associated with differences in temperature, and the warmth of the spot's base explains the ferocious winds we see at the top of the atmosphere."

Juno has also detected hundreds of lightning discharges that gave off radio waves in the megahertz and gigahertz ranges, far more energetic than Earth's own. In results reported June 2018, its Waves instrument recorded four lightning strikes every second.

Shallow lightning originating from ammonia-water clouds and giant, slushy hailstones rich in ammonia-ice, known as mushballs, were detailed in research published August 2020. And in October 2020, researchers reported that Juno had found signs of sprites and elves — brief, unpredictable electrical flashes of light associated with thunderstorms — the first to be seen on a world other than our own.

Chance of mushballs// Pop-up clouds are thought to be the source of Jupiter's powerful thunderstorms. They can generate shallow lightning and mushballs — slushy hailstones made of water and ammonia — as depicted in this artist's concept based on Juno data. NASA/JPL-CALTECH/SWRI/MSSS/GERALD EICHSTÄDT/HEIDI N. BECKER/KOJI KURAMURA



A striking scene// A stormy planetscape dotted with lightning strikes is rendered in this photoillustration combining a JunoCam image with artistic additions. At times, Juno recorded lightning at the rate of four strikes per second. NASA/JPL-CALTECH/SWRI/JUNOCAM

Time extension

While Juno's mission was originally scheduled to end in 2018, the craft remains so productive that its mission has been extended twice: first to July 2021 and again through September 2025, or until it reaches the end of its life.

These mission extensions have enabled it to take aim not just at Jupiter, but also its large moons Ganymede, Europa, and volcanic Io. One flyby in June 2021 saw Juno pass within just 645 miles (1,038 km) of Ganymede — closer than any spacecraft in a generation — and return spectacular infrared imagery of its icy north pole.

The gravity-assisted tweaks afforded by repeat flybys of these moons in the coming years will naturally reshape Juno's orbit. Last year's close Ganymede passage reduced the spacecraft's orbital period from 53 to 43 days, with a Europa flyby in September 2022 expected to shave this down to 38 days. Two Io encounters, one in December 2023 and a second in February 2024, will cut it further to 33 days.

As a result, Juno's most remarkable discoveries may be still to come. And a probe expected to survive just two years immersed in Jupiter's fearsome radiation may spend almost a full decade stripping back the secrets of this most secretive of worlds. "We are not looking for trouble," promised Scott Bolton. "We are looking for data." If she could know what her robotic namesake has achieved, the all-seeing Juno of myth would be justly proud. But her philandering husband, surely, would be less than thrilled.

Ben Evans *has been fascinated by space since childhood. He has written extensively on the history of human spaceflight.*

Catch PLUTO this summer

Planet or not, Pluto is a worthy target.

BY MICHAEL E. BAKICH

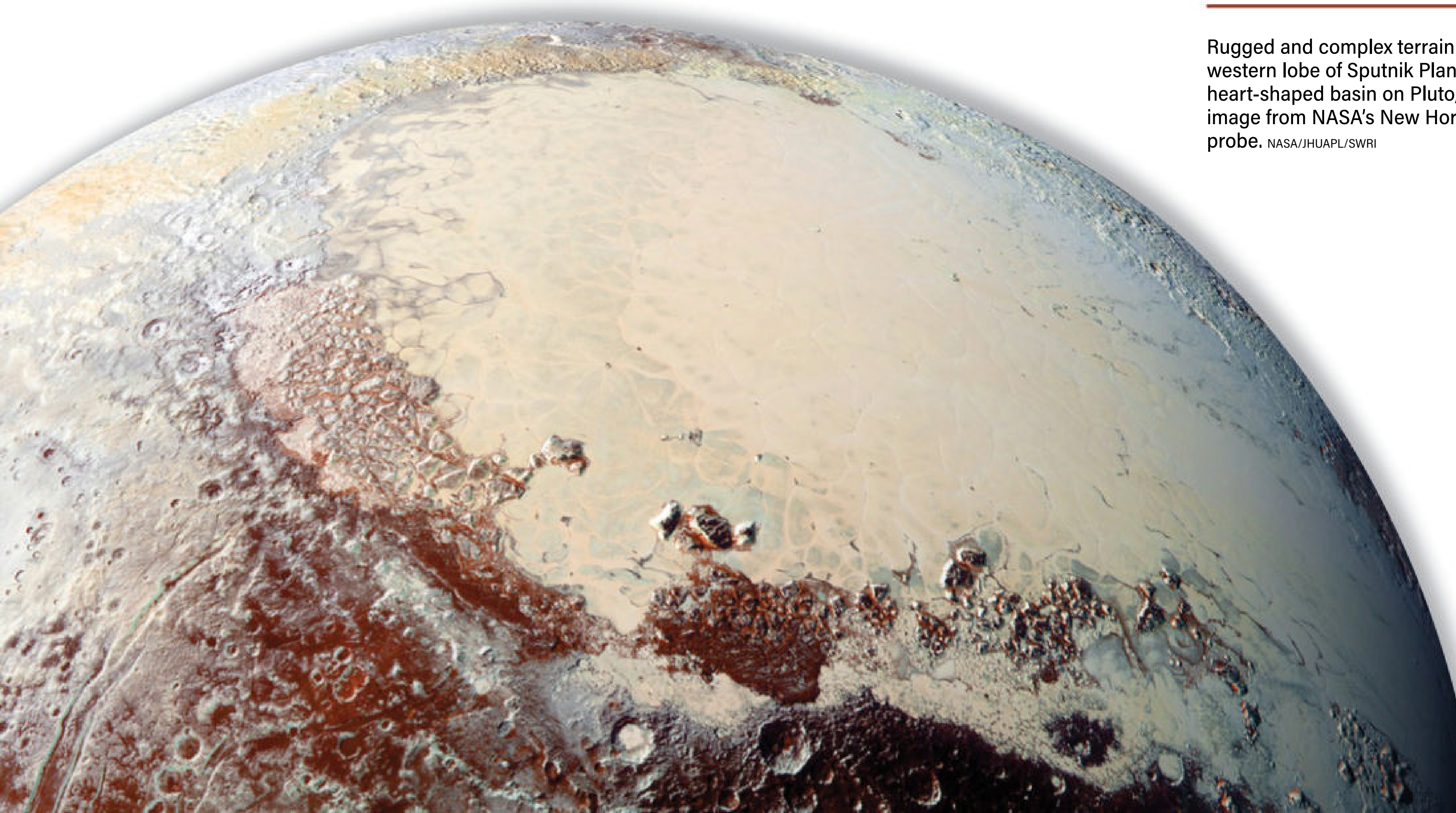
IN 1929, Clyde William Tombaugh, a farm boy who grew up in Illinois and Kansas, began working at Lowell Observatory in Flagstaff, Arizona. The director of the facility, renowned astronomer Vesto Slipher, had hired Tombaugh based on some high-quality sketches of Jupiter and Mars he sent to the observatory.

Tombaugh's job was to search for Planet X, a world that some astronomers believed existed beyond Neptune. Using the observatory's 13-inch astrograph, Tombaugh exposed hundreds of glass plates. His search strategy involved photographing the same region of sky several days apart and then using a machine called a blink comparator to see if any objects on the plates moved. It took him only until January 1930 to stumble onto Pluto.

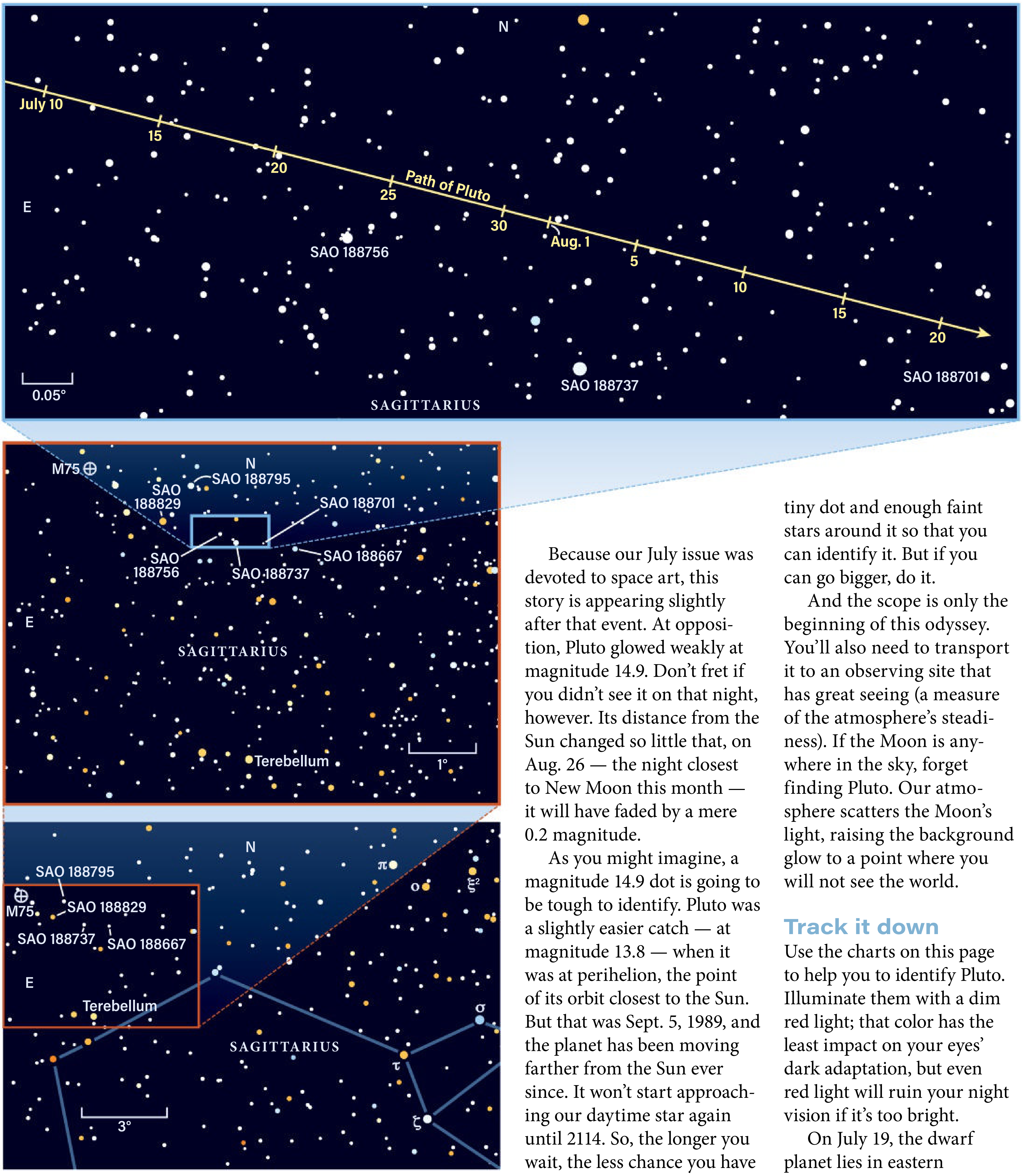
Since then, amateur astronomers have regarded observing the distant, ever-so-faint world as a badge of honor. If you haven't seen Pluto, this month offers yet another chance to tick it off your bucket list.

Be prepared

Pluto reached opposition at 2h UT on July 20. Observers always target planets (especially those beyond Saturn) near opposition because that's when they appear brightest. At that point, because the planet lies opposite the Sun in our sky, it rises at sunset, climbs highest at midnight, and sets at sunrise.



Rugged and complex terrain lines the western lobe of Sputnik Planitia, a heart-shaped basin on Pluto, in this image from NASA's New Horizons probe. NASA/JHUAPL/SWRI



Start your search for Pluto with the wide-field view of Sagittarius (bottom), which shows stars down to magnitude 8, including the Teapot asterism at right. Locate Tau (τ) Sagittarii, the lower left corner of the Teapot's handle, and then move to Terebellum, 11° east. In the binocular view (middle), stars are shown down to magnitude 10. You should be able to find the magnitude 7.6 star SAO 188737 just over 3° north of Terebellum. On July 19, Pluto will be approaching a tiny triangle of stars; the telescopic view (top) includes stars as faint as magnitude 16. ALL MAPS: *ASTRONOMY*: ROEN KELLY

Because our July issue was devoted to space art, this story is appearing slightly after that event. At opposition, Pluto glowed weakly at magnitude 14.9. Don't fret if you didn't see it on that night, however. Its distance from the Sun changed so little that, on Aug. 26 — the night closest to New Moon this month — it will have faded by a mere 0.2 magnitude.

As you might imagine, a magnitude 14.9 dot is going to be tough to identify. Pluto was a slightly easier catch — at magnitude 13.8 — when it was at perihelion, the point of its orbit closest to the Sun. But that was Sept. 5, 1989, and the planet has been moving farther from the Sun ever since. It won't start approaching our daytime star again until 2114. So, the longer you wait, the less chance you have of bagging this elusive quarry.

Let me be honest here. An 8-inch telescope will give great views of clusters, nebulae, and some galaxies — but not Pluto. To track it down, you need to think bigger. An 11-inch scope will reveal the tiny dot and enough faint stars around it so that you can identify it. But if you can go bigger, do it.

And the scope is only the beginning of this odyssey. You'll also need to transport it to an observing site that has great seeing (a measure of the atmosphere's steadiness). If the Moon is anywhere in the sky, forget finding Pluto. Our atmosphere scatters the Moon's light, raising the background glow to a point where you will not see the world.

Track it down

Use the charts on this page to help you to identify Pluto. Illuminate them with a dim red light; that color has the least impact on your eyes' dark adaptation, but even red light will ruin your night vision if it's too bright.

On July 19, the dwarf planet lies in eastern Sagittarius, about 2° from that constellation's border with Capricornus. It also lies 2° west-southwest of globular cluster M75, which is worth a look through a medium to large telescope. Pluto's right ascension is 19h58m, and its

ABOVE: The haze layers of Pluto's thin but complex atmosphere are backlit in this view from NASA's New Horizons probe. NASA/JHUAPL/SWRI

RIGHT: Clyde Tombaugh got his start as an astronomer by building his own telescopes and observing from his family's farm in Kansas. NMSU LIBRARY ARCHIVES AND SPECIAL COLLECTIONS

declination is –22°50'. The planet first entered Sagittarius in December 2006 and reaches Capricornus in early 2024.

Start with the wide-field view at the bottom of page 26 and identify the Teapot, the eight stars that make up Sagittarius' main asterism. From magnitude 3.3 Tau (τ) Sagittarii, the star in the lower left corner of the Teapot's handle, move 11° east to magnitude 4.7 Terebellum (Omega [ω] Sagittarii). It's part of a group of four similarly bright stars.

From Terebellum, move slightly more than 3° north and find the magnitude 7.8 star SAO 188737. Pluto now will lie within the eyepiece, a mere 25' northeast of that star. To get there, look 15' to the northeast for magnitude 8.9 SAO 188756. (Note that these instructions are for those without computerized drives. If your telescope sits atop a go-to drive, all SAO stars are probably in its database. So, just enter "SAO 188756" and hit "Go To.")

SAO 188756 anchors a trio of stars, all brighter than Pluto, angling northwest. Just to the northeast is a smaller and fainter but similarly angled trio of stars. It forms one side of an equilateral triangle with a star of nearly the same brightness. The faintest of this group just barely outshines your target. If you locate these stars early in the evening and return to this view six or eight hours later (owners of motorized telescope drives can just leave them on), you may notice that one object has changed its position. That's Pluto.

It's tough to remember such fine details, however, especially when a plethora of stars surrounds the ones you're trying to target. A much better strategy is to sketch the region. Then come back to it a few hours later. Even better, return the following night (or two or three nights later), and re-sketch. Pluto will be the only point of light whose position is different. If you do return several nights later, remember to allow the Moon to set. The main chart on page 26 shows background stars to magnitude 16, so you should be able to locate Pluto, which glows slightly brighter than this limit. Be patient, though: This isn't a sight that will instantly reveal itself to you.

Also, remember that Pluto is moving westward. Outer planets generally move to the east through the stars. But around opposition, Earth, in its orbit, passes Pluto, causing it to appear to travel west. This apparent reversal is called retrograde motion.

Pluto is an object that every amateur astronomer should see. Even though the process is a bit difficult, you'll feel a sense of accomplishment having done it. Good luck!

Michael E. Bakich *is a contributing editor of* Astronomy *who co-authored* Atlas of Solar Eclipses: 2020–2045 *with Michael Zeiler.*

SCOPES for city-dwellers

Don't let bright lights prevent you from exploring cosmic sights.

BY PHIL HARRINGTON

MANY ASTRONOMY enthusiasts live under the veil of light pollution, either from local sources like poorly aimed lights on neighboring houses or the enormous light domes enveloping large cities. It can be quite discouraging at first.

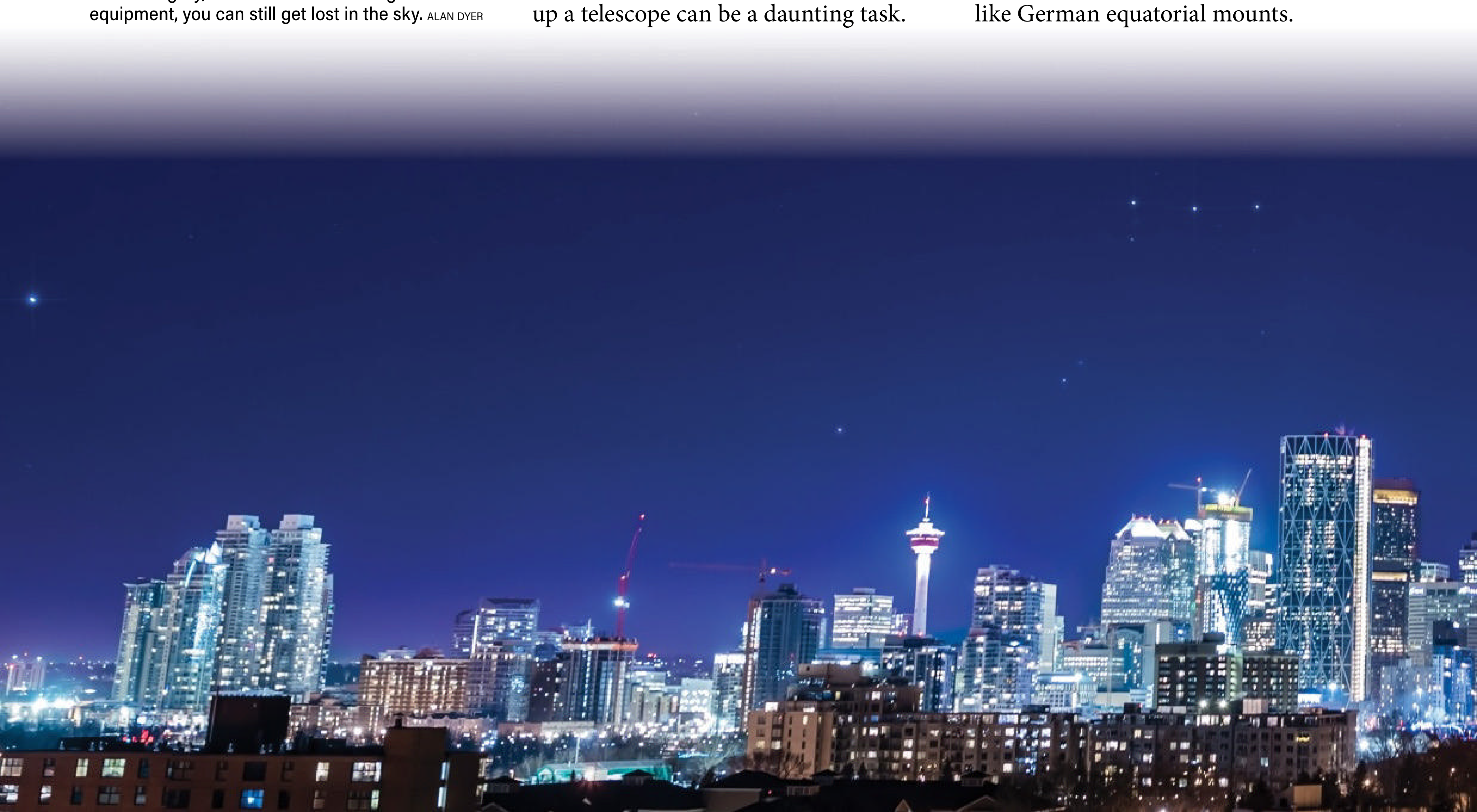
But it doesn't mean you can't be an active observer. Anyone can enjoy wonderful views every clear evening without venturing far from home. You just need to know what telescope is best for you and your location.

When it comes to buying a telescope, most people immediately consider their budget. No one wants to spend beyond their means. But for those who live in a city, there are a few other matters to ponder, as well. The most important considerations are ease of use and storage. Unless a telescope is convenient to use, it will quickly become consigned to the closet. Many a stargazer's enthusiasm has turned to apathy upon the harsh realization that hauling out and setting up a telescope can be a daunting task.

So, where will you keep your telescope when it is not in use? If you must lug the equipment up and down stairs every night, you'll want to be able to carry it all in one trip. The same applies if you need to walk or take public transport to a nearby park or other open area. If, however, you have first-floor access and a yard of your own with a clear view, then taking couple of trips is less burdensome.

Also remember that you won't just be transporting the telescope, but its mount as well. If you must haul the setup a significant distance, avoid heavier designs like German equatorial mounts.

City light pollution largely washes out the stars above Calgary, Alberta. But with the right equipment, you can still get lost in the sky. ALAN DYER



TELESCOPE IMAGES IN ORDER: HIGH POINT SCIENTIFIC; CELESTRON; CELESTRON; EXPLORE SCIENTIFIC; IOPTRON; SKYWATCHER USA; STELLARVUE; TELE VUE; TELE VUE; MEADE

Fortunately, nowadays there are many small mounts that are light enough to easily carry, yet sturdy enough to support a portable telescope. The lightest, most compact mounts are altitude-azimuth designs. With these, the telescope moves up and down in altitude and left to right in azimuth, which might be more intuitive for novice observers.

Many setups also feature computerized go-to mounts, which automatically aim the telescope toward a preselected object. That's a big plus if light pollution obliterates everything fainter than the Moon and brighter planets and stars. But be aware that a go-to mount's "brain" must first know its location, as well as the time and date, before it will work. In some cases, you will need to manually input that information and go through a one- or two-star alignment process using pre-selected bright stars. Other systems automatically complete all that using GPS technology.

For more details on the different types of telescopes, see my article, "First scopes for adults," in the June 2022 issue. But for now, here are 10 scopes, arranged in alphabetical order, that might serve you well when viewing the sky from an urban environment.

1 Apertura AD8 Dobsonian

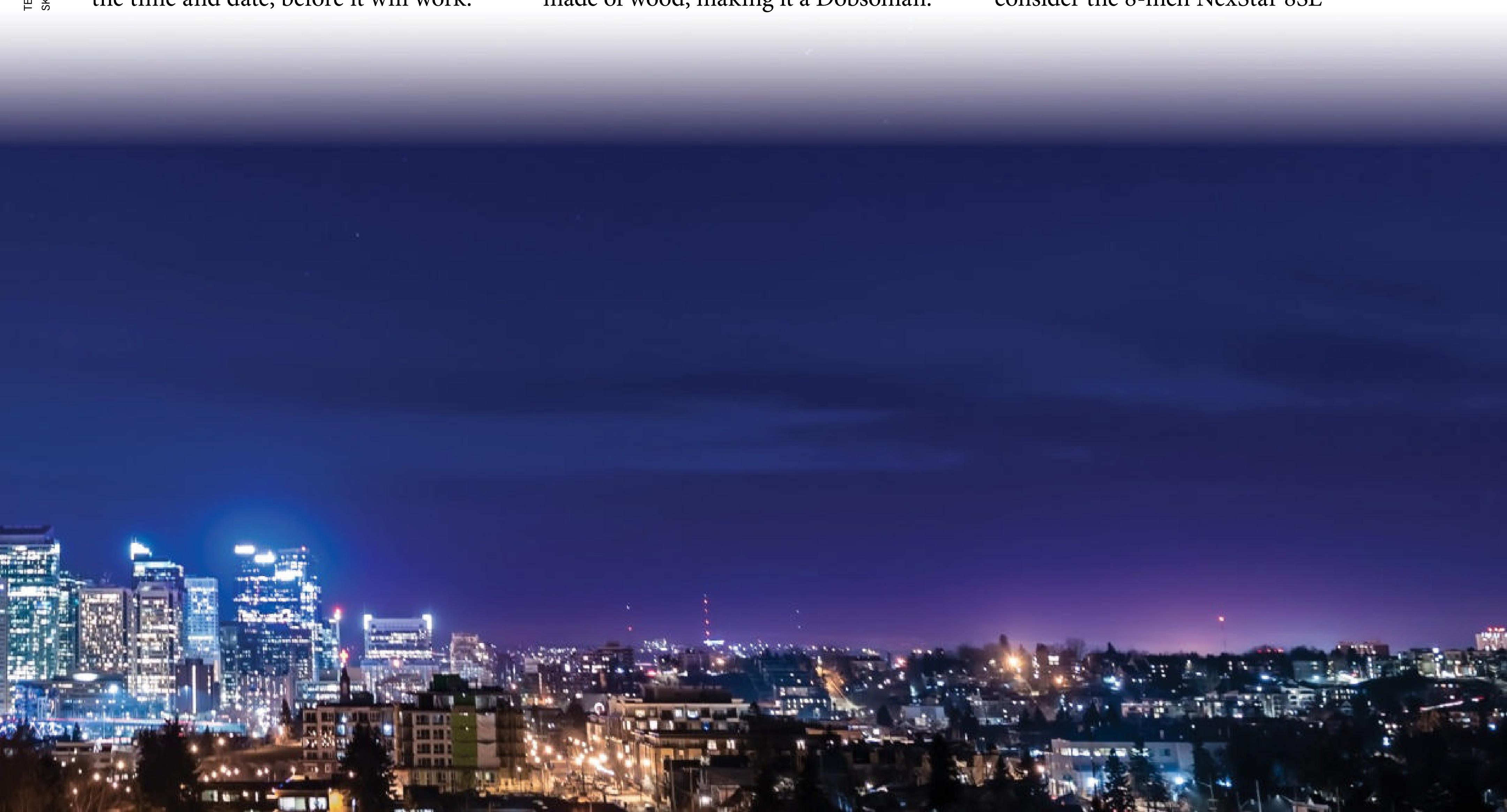
This 8-inch Newtonian reflector rides on a simple altitude-azimuth mount made of wood, making it a Dobsonian. Fully assembled, it weighs 52.2 pounds (23.7 kilograms), so it's an excellent choice for those who don't have to carry their telescope up and down flights of stairs.

2 Celestron NexStar Evolution 6

This portable 6-inch Schmidt-Cassegrain telescope comes on a one-armed computerized mount with a built-in battery that lasts up to 10 hours on a single charge. The total kit weighs 38 pounds (17.2 kg) and features an integrated handle for easy carrying.

3 Celestron NexStar 8SE

If you have a bigger budget, consider the 8-inch NexStar 8SE



Earth's city lights are on full display in this image created using data from orbiting Defense Meteorological Satellite Program (DMSP) craft.
DATA: MARC IMHOFF (NASA/GSFC), CHRISTOPHER ELVIDGE (NOAA/NGDC); IMAGE: CRAIG MAYHEW, ROBERT SIMMON (NASA/GSFC).

Schmidt-Cassegrain. The telescope attaches to its computerized, single-armed altitude-azimuth mount using a dovetail plate for easy setup.

4 Explore Scientific Explore FirstLight 102mm Doublet Refractor

This 102mm refractor has enough aperture to reveal the Moon, brighter planets, binary stars, and bright deep-sky objects, but is still small enough to easily transport.

5 iOptron SmartStar Cube-A-MC90

iOptron's innovative CubePro mount (not shown) paired with their compact 90mm Maksutov-Cassegrain scope creates an advanced, highly portable system small enough to carry onboard airplanes.

6 Sky-Watcher SkyMax 127 AZ-GTi

This 127mm Maksutov-Cassegrain weighs 9.7 pounds (4.4 kg), and measures 15 inches (38 cm) long, so is easy to carry and store. It sits atop the AZ-GTi altitude-azimuth go-to mount, which adds another 8.6 pounds (3.9 kg) to the package.

7 Stellarvue Triplet Apo SVX080T-25FT

The Stellarvue SVX080T-25FT refractor features a 3.1-inch (80 mm) three-element apochromatic objective lens, which eliminates the chromatic aberration that can plague traditional achromatic refractors. The scope's image quality is exceptional, but note the mount is sold separately.

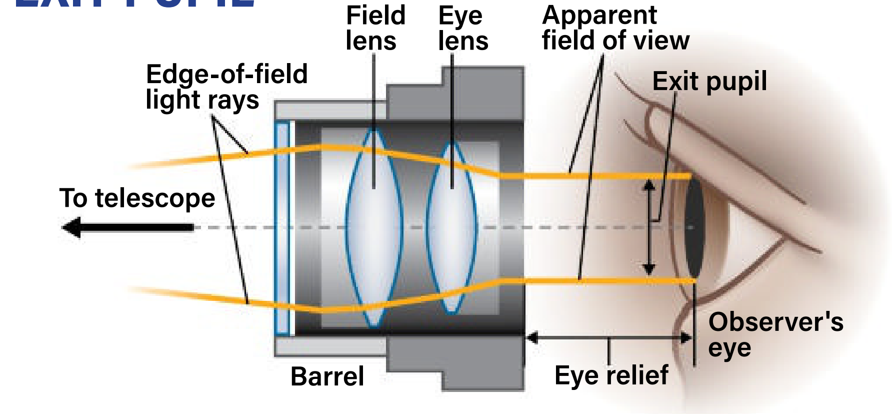
8 Tele Vue-NP101is

You can achieve breathtaking views and images with this 101mm NP101is refractor, thanks to its four-element apochromatic objective lens system. The mount is sold separately.

9 Tele Vue-85

The 85mm TV-85 refractor from Tele Vue combines portability, craftsmanship, and excellent optics in a small package. Again, the mount is sold separately.

EXIT PUPIL



The exit pupil is the diameter of the cylinder of light that leaves an eyepiece and enters your eye. Choosing the optimal exit pupil depends on what type of target you are observing. *ASTRONOMY*: ROEN KELLY, AFTER PHIL HARRINGTON

TARGET TYPE	EXIT PUPIL (mm)
Large star clusters, full lunar disk	3 to 4
Small deep-sky objects (especially planetary nebulae and smaller galaxies), double stars, lunar details, and planets on nights of poor seeing	1 to 3
Double stars, lunar details, and planets on exceptional nights	0.5 to 1

10 Meade Coronado Personal Solar Telescope

Let's not forget about solar observing, especially as we rise out of the doldrums of solar minimum. A dedicated Hydrogen-alpha (Hα) solar scope, such as the 40mm Meade Coronado Personal Solar Telescope, will reveal amazing details, including prominences, filaments, and active regions. (Remember: Never observe the Sun without proper equipment!)

Make the most of your observing session

No matter what you choose, to get the best out of your urban scope, you'll want to optimize it with a few simple tricks. One of the most helpful techniques to enhance the view is to add a short tube extension, called a dew shield, to the front of the telescope. The extension slows dew formation on the lens or corrector plate, as well as blocks stray light from entering from the side. The latter is especially important for Newtonian reflectors because the focuser is so close to the front of the tube. Make a slip-on dew shield that extends at least one telescope-tube diameter in front of the focuser and paint the inside of the tube flat black to dampen reflections.

Additionally, amateurs often overlook the importance of eyepieces. While many purchase eyepieces based on their focal lengths and the resulting magnification for a given telescope, the real key is exit pupil. The exit pupil is the diameter of the cylinder of light exiting the eyepiece and entering your eye. The size of the exit pupil will change as magnification changes.

Depending on which type of target you are interested in observing, using the right eyepiece combination to get the optimal exit pupil will really enhance your view. See the table above for some suggestions.

To find out how large the exit pupil will be with a specific telescope/eyepiece combination, divide the focal length of the eyepiece in millimeters by the telescope's focal ratio (its f/ number, which has no units). Let's say you have a 6-inch f/10 Schmidt-Cassegrain and a 12mm eyepiece. That combination yields an exit pupil of 1.2 mm (12 mm/10).

As you are selecting eyepieces, make sure they include rubber eyecups. Eyecups are designed to block localized light from entering the corner of the observer's eye, and they can be a game-changer.

Also be sure to use a broadband light pollution reduction (LPR) filter. Many outdoor lights do not shine uniformly across the entire visible spectrum. Instead, they emit light at only a few discrete wavelengths. For instance, high-pressure sodium streetlights principally shine in the yellow wavelengths. LPR filters suppress the broad portion of the visible spectrum that includes those wavelengths, while allowing others to pass through. Unfortunately, they are not as effective against incandescent bulbs and LED lights, since those emit across the entire spectrum. LRP filters may not magically whisk you away to that perfect dark sky, but they will go a long way toward darkening your field of view and improving contrast.

Urban stargazing can be great fun with the right equipment. With a bit of consideration and preparation, you'll be treated to years of entertainment viewing the sky — without hours of travel.

Phil Harrington *is a longtime contributor to* Astronomy *and the author of many books.*

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING


The solar system's giant planets take center stage on August nights. The time is ripe to look for stunning detail in the rings of Saturn (left) and on Jupiter's disk (right). ARIEL ADORNO

AUGUST 2022
Giant planet time

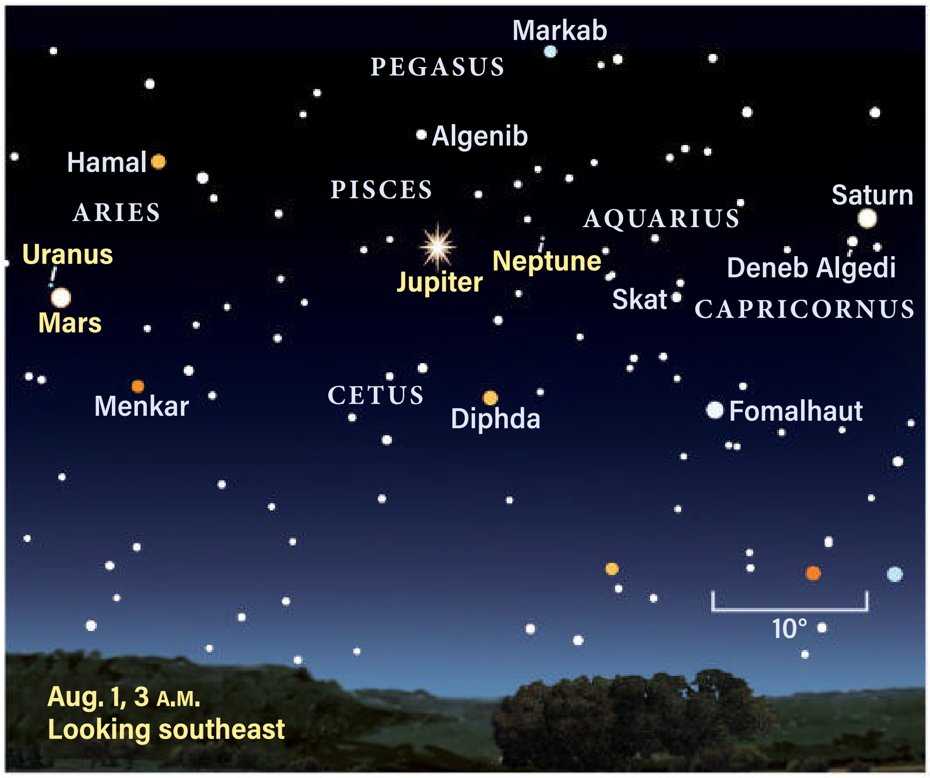
Midsummer observing means giant planets, with Jupiter and Saturn visible before midnight. Both planets offer hours of amazing views. Saturn is visible all night, while Jupiter rises a bit later. You might catch elusive Mercury in the early evening if you're lucky. And the morning sky carries the glories of a growing Mars and a brilliant Venus.

Mercury modestly hugs the western horizon all month. It's a favorable apparition for Southern Hemisphere observers but is more challenging for those in the Northern Hemisphere. On Aug. 3, soon after sunset, you'll find it only 0.8° north of Regulus, although the pair sets within an hour of the Sun. Try 30 minutes after sunset to spot magnitude –0.5 Mercury 4° high; use binoculars to find fainter Regulus.

Mercury's elevation after sunset doesn't improve much as August progresses, although its elongation from the Sun increases. Mercury slides southward along the horizon. By Aug. 14, it fades to magnitude 0 and stands 5° high due west 30 minutes after sunset.

Mercury reaches greatest eastern elongation Aug. 27 and fades to magnitude 0.3 — difficult to see in bright twilight. Try spotting it in binoculars on the 28th and 29th, as a crescent Moon enters the scene. Mercury lies 9.5° left of the Moon on the 28th and 6.5° below the Moon on the 29th.

Get an early start



As August opens, Mars and Uranus sit 1.4° apart in the predawn sky. Center binoculars on Mars to find the more distant ice giant. Also visible are Jupiter, Neptune (requires binoculars), and Saturn. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Saturn rises in the east soon before 9 P.M. local time on Aug. 1. It reaches opposition Aug. 14, so it is visible all night. The best time to view the planet is when it is highest in the southern sky, around 1 A.M. local time (local midnight using daylight saving time). It briefly brightens to magnitude 0.2 midmonth and is unmistakable within Capricornus the Sea Goat as the brightest object in this part of the sky.

You'll find 3rd-magnitude Deneb Algedi (Delta [δ] Capricorni) near Saturn, 1.7° southeast of the planet as August opens. Saturn's retrograde motion is easy to spot as the ringed planet wanders slowly westward at about 0.5° per week. August's Full Moon, also opposite the Sun in the sky, lies within 5° of Saturn overnight on Aug. 11/12, shortly before the Perseid meteor shower peaks.

It's the best time of the year to view Saturn's rings, since the planet is closest to Earth at opposition (824 million miles), rendering the planet and its ring system at their largest apparent size to Earth dwellers. Saturn's disk spans 19" across the

OBSERVING HIGHLIGHT

SATURN reaches opposition Aug. 14 and is visible all night this month.

equator, but only 17" from pole to pole — the planet's somewhat flattened disk is now evident as the tilt of the rings reveals more of the southern polar regions.

The rings span nearly 43" across and 10" along the minor axis. Compare this year's view to last summer's, and you'll notice the distinct change in ring tilt. By 2025, the rings will appear edge-on.

Titan, Saturn's largest moon, is an easy target for small scopes. You'll find it north of Saturn Aug. 5 and 21, and due south Aug. 13 and 29. On Aug. 19, a field star slightly dimmer than Titan's magnitude 8.5 appears southwest of the planet; don't confuse it for the moon, which lies southeast.

Closer to the rings, 10th-magnitude Tethys, Dione, and Rhea orbit with periods ranging from two to five days.

Two-toned Iapetus' leading hemisphere is dark, causing the moon to appear faint at eastern elongations (12th magnitude) and brighter at western ones (10th magnitude). This month, Iapetus is brightest Aug. 7, when it reaches western elongation 9' west of Saturn. It moves to superior conjunction early Aug. 27 for U.S. observers.

Usually, Iapetus skims past the northern hemisphere of Saturn's disk, but the current shallow tilt of its orbital plane causes an occultation instead. It's a

— Continued on page 38

RISING MOON | Historic record

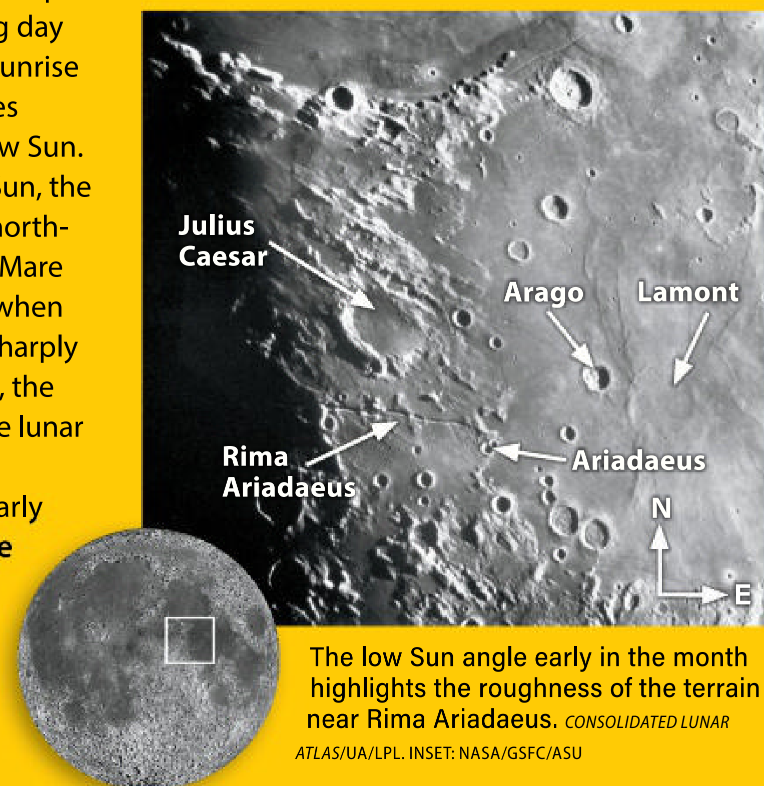
THE UPRIGHT crescent Moon that opened August waxes into a world of striking detail up and down the terminator, the line dividing day from night. The hours shortly after lunar sunrise exaggerate the apparent height of features thanks to the long shadows cast by the low Sun.

Along the curved limb under a higher Sun, the topography seems to have vanished. The north-south wrinkle ridges crossing the plains of Mare Tranquillitatis really stand out on the 2nd, when sunlight first touches the ramparts of the sharply defined crater Arago. Just to the southeast, the rim of the buried crater Lamont buckles the lunar surface.

By the 3rd, the Moon's illumination nearly matches this image. How did nature create this weird landscape? Scientists have pieced together the likely story that an asteroid slammed into the young Moon, carving out a huge, deep basin. Later, smaller impactors scooped out the 50-mile-wide Julius Caesar and others, including Lamont. Several times lava welled up through cracks in the larger basin, flooding it. Because Julius Caesar formed on a slope, its eastern rim was lower, allowing the rising lava to breach that wall but not the higher western one. Its central peak was swallowed. Much later, a smattering of impacts dotted the solidified Sea of Tranquillity.

The long line to the south of Julius Caesar is Rima Ariadaeus (pronounced Ah-ree-ah-day-us), called the Ariadaeus rille. It is a collapsed valley a half-mile deep created as two zones pulled apart. A number of shallower rilles extend parallel to the shores of Tranquillity. Ariadaeus Crater is the larger of the snowmanlike doublet at the rille's east end. Return the following night, the 4th, when the equally interesting Hyginus rille to the west is revealed. Note how the wrinkles near Arago have vanished under the higher Sun, while Rima Ariadeus is in the act of disappearing.

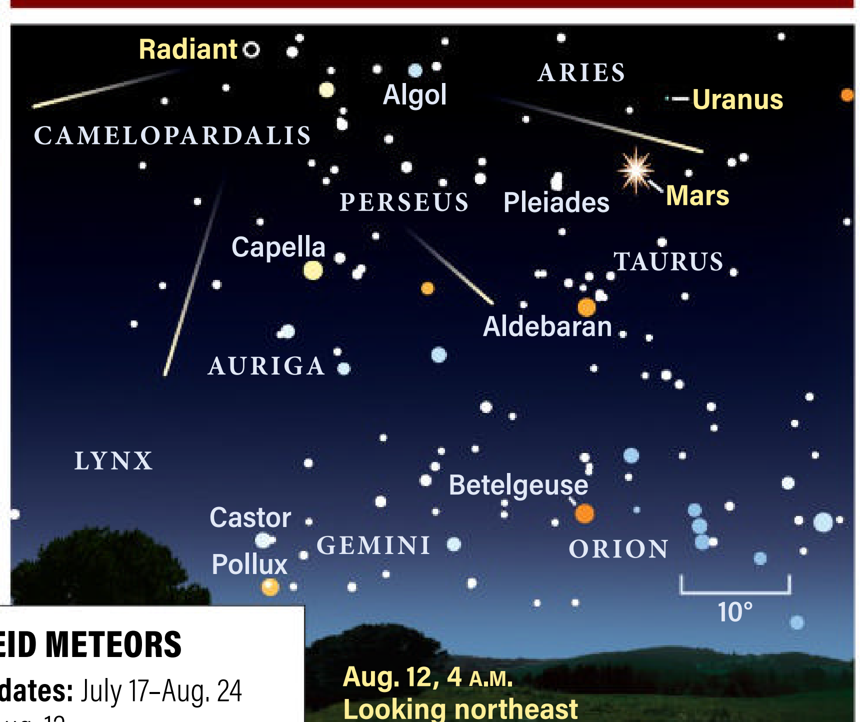
Julius Caesar and Rima Ariadaeus



The low Sun angle early in the month highlights the roughness of the terrain near Rima Ariadaeus. CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | The brightest prevail

Perseid meteor shower



Focus on catching Perseid meteors in the last hour before morning twilight, when you're on Earth's leading hemisphere.

PERSEID METEORS
Active dates: July 17–Aug. 24
Peak: Aug. 12
Moon at peak: Waxing crescent
Maximum rate at peak: 100 meteors/hour

THIS YEAR'S famous Perseid meteor shower is heavily affected by a Full Moon one day before maximum on Aug. 12. Its light hides all but the brightest meteors, severely attenuating hourly rates. The Perseids are active from July 17 through Aug. 24. The radiant in Perseus rises late at night, reaching a respectable 60° altitude by 4 A.M. local time.

The more favorable time this year to view the Perseids is the few days prior to the peak. Each day before Aug. 12 will give you an extra hour of moonless predawn skies. For example, on Aug. 10, the Moon sets by 4 A.M. local time, with nearly an hour before twilight begins.

Don't forget that the occasional Perseid fireball whistles through our atmosphere; even with a Full Moon, these will be hard to miss.

STAR DOME

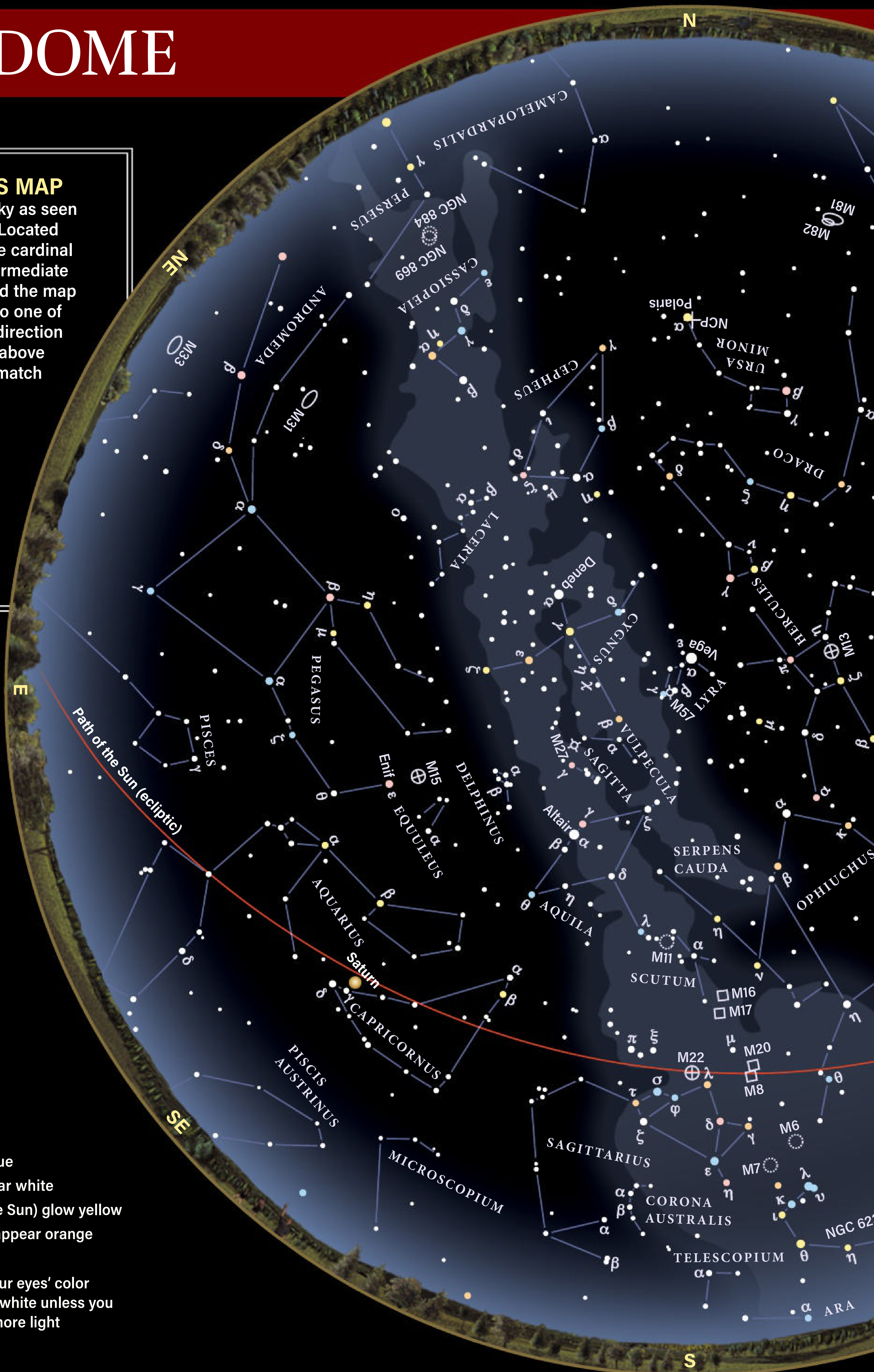
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

11 P.M. August 1
10 P.M. August 15
9 P.M. August 31

Planets are shown at midmonth



MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

AUGUST 2022

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 Mars passes 1.4° south of Uranus, 5 A.M. EDT

4 Mercury passes 0.7° north of Regulus, 1 A.M. EDT

5 First Quarter Moon occurs at 7:07 A.M. EDT

7 Venus passes 7° south of Pollux, 6 A.M. EDT

10 The Moon is at perigee (223,587 miles from Earth), 1:09 P.M. EDT

11 Full Moon occurs at 9:36 P.M. EDT

The Moon passes 4° south of Saturn, midnight EDT

12 Perseid meteor shower peaks

14 The Moon passes 3° south of Neptune, 6 A.M. EDT

Saturn is at opposition, 1 P.M. EDT

15 The Moon passes 1.9° south of Jupiter, 6 A.M. EDT

18 The Moon passes 0.6° north of Uranus, 11 A.M. EDT

19 Last Quarter Moon occurs at 12:36 A.M. EDT

The Moon passes 3° north of Mars, 8 A.M. EDT

22 Asteroid Vesta is at opposition, 3 P.M. EDT

The Moon is at apogee (251,915 miles from Earth), 5:52 P.M. EDT

24 Uranus is stationary, 11 A.M. EDT

25 The Moon passes 0.7° south of dwarf planet Ceres, 3 P.M. EDT

The Moon passes 4° north of Venus, 5 P.M. EDT

27 New Moon occurs at 4:17 A.M. EDT

Mercury is at greatest eastern elongation (27°), noon EDT

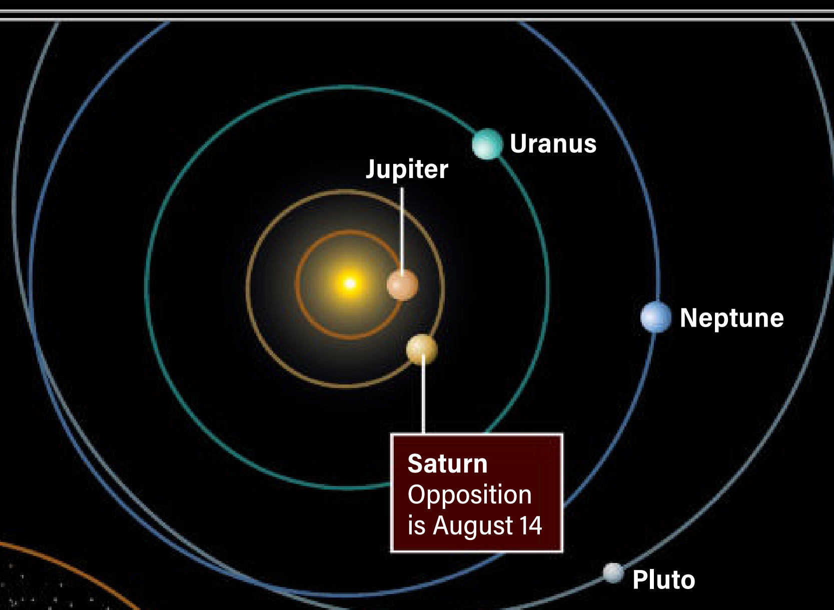
29 The Moon passes 7° north of Mercury, 7 A.M. EDT

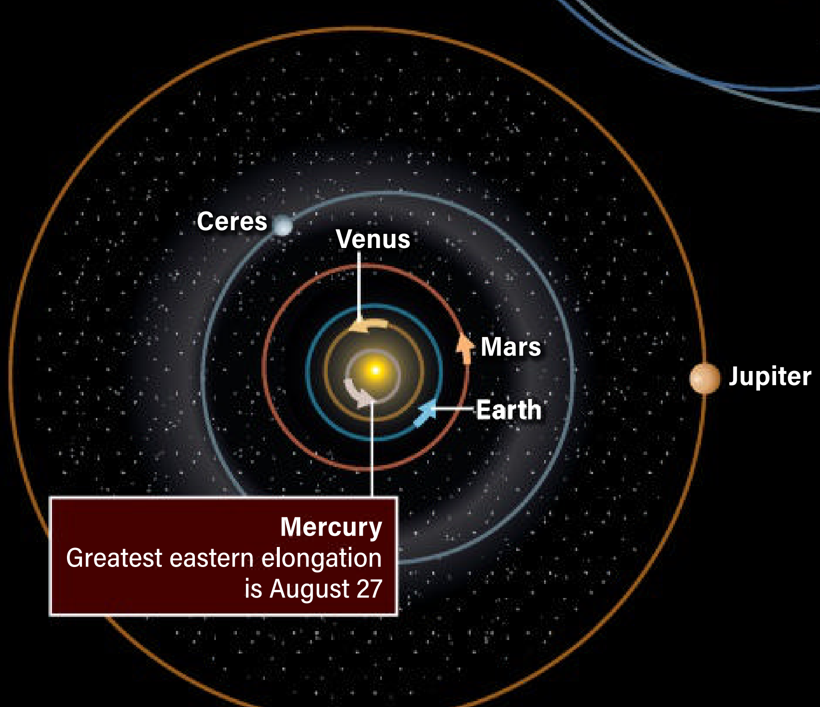
PATHS OF THE PLANETS

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

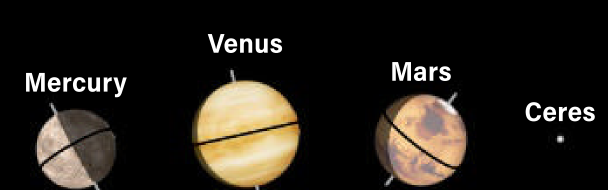
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

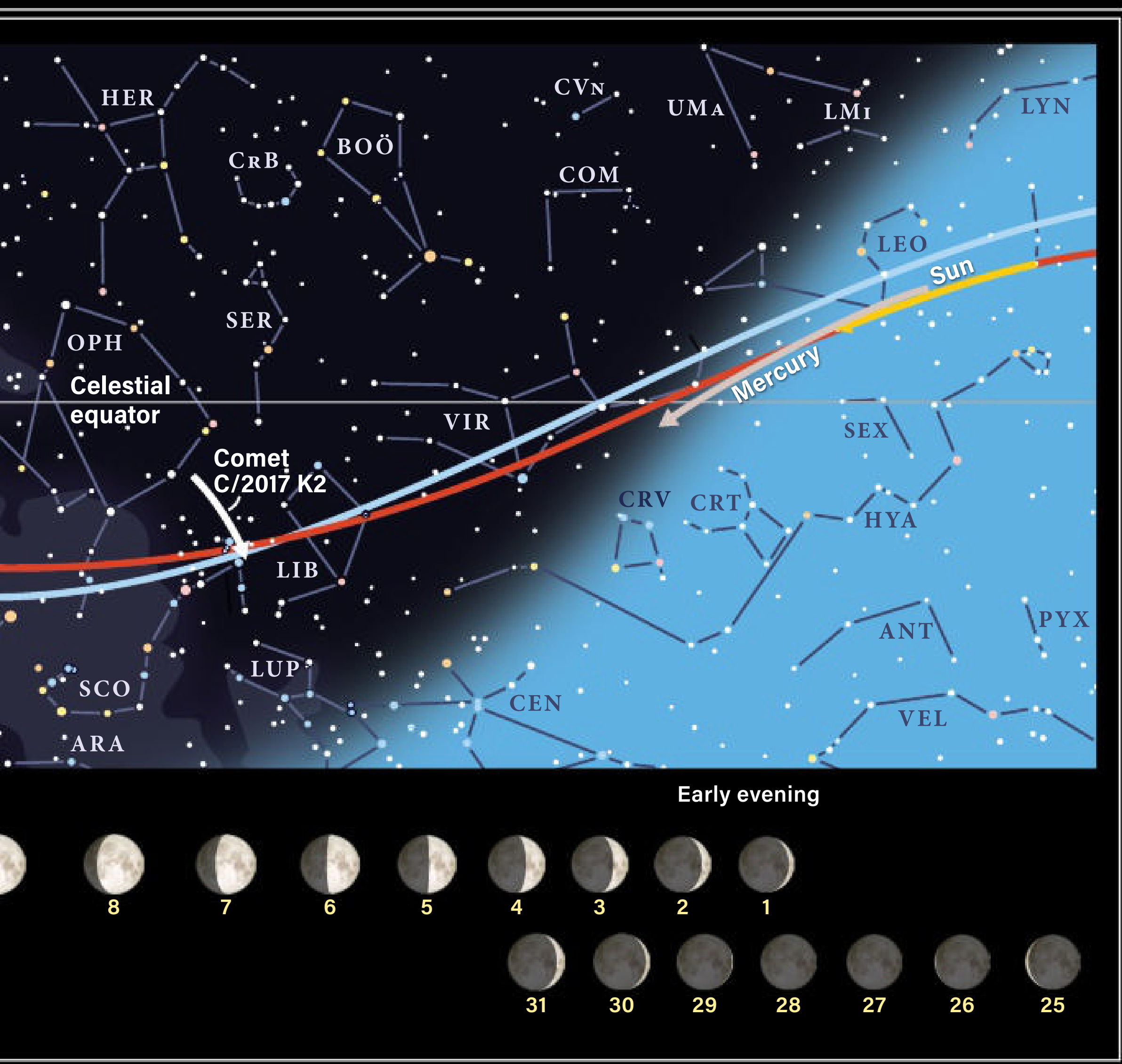
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	Aug. 31	Aug. 15
Magnitude	0.4	–3.9
Angular size	7.7"	10.4"
Illumination	48%	95%
Distance (AU) from Earth	0.878	1.608
Distance (AU) from Sun	0.460	0.719
Right ascension (2000.0)	12h11.1m	8h24.3m
Declination (2000.0)	–4°12'	19°52'

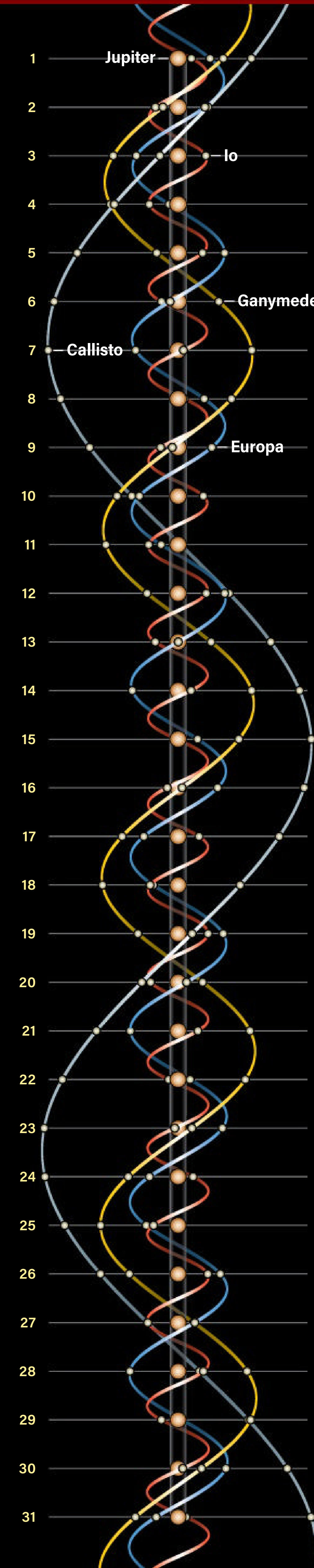
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

AUGUST 2022

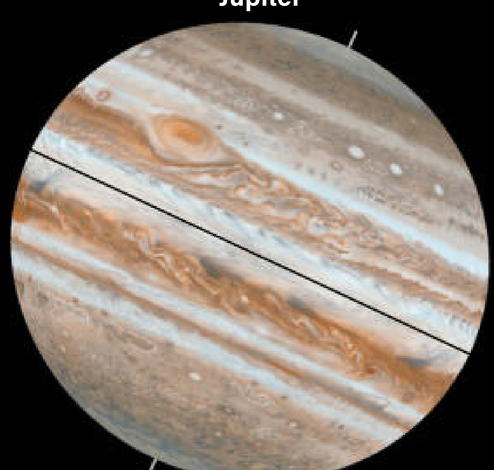


JUPITER'S MOONS

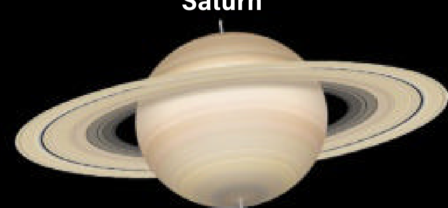
Dots display positions of Galilean satellites at 4 A.M. EDT on the date shown. South is at the top to match the view through a telescope.

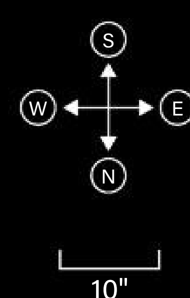


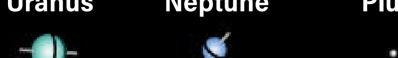
Jupiter



Saturn

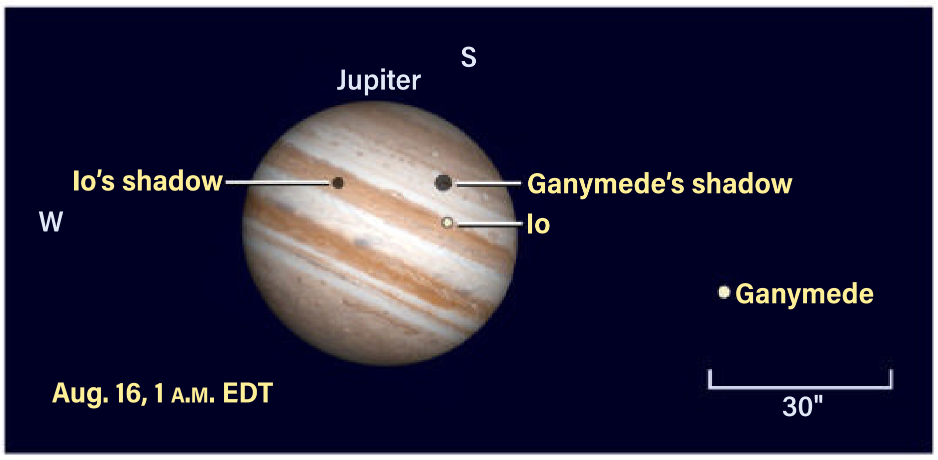






MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15
0.0	8.6	–2.8	0.2	5.8	7.7	15.1
8.9"	0.4"	46.9"	18.8"	3.6"	2.4"	0.1"
85%	100%	99%	100%	100%	100%	100%
1.055	3.547	4.202	8.857	19.606	29.058	33.688
1.402	2.572	4.958	9.869	19.690	29.916	34.584
3h38.3m	8h54.6m	0h31.5m	21h37.5m	3h04.9m	23h41.9m	19h55.6m
17°52'	23°03'	1°45'	–15°33'	17°00'	–3°17'	–22°59'

Kepler's laws in motion



The dual transit of Io and Ganymede (and their shadows) Aug. 15/16 highlights these moons' orbital motion. Europa and Callisto lie farther east at this time.

challenging event, given the brightness of Saturn and its rings, combined with Iapetus' paltry 11th-magnitude glow. Digital imaging is likely to best capture the event. Iapetus lies just above the rings and begins to disappear around 12:25 A.M. EDT Aug. 27 (late on Aug. 26 in all other U.S. time zones).

Other moons also undergo eclipses and transits across the planet's disk; these will increase over the next few years.

Neptune is an easy binocular object at magnitude 7.7. It starts the month in southwestern Pisces, 5° due south of Lambda (λ) Piscium, the Circlet's southeasternmost star. You can also home in on Neptune by looking 13.5° southwest of Jupiter. The region is best viewed starting a couple of hours after midnight, when Neptune rises above 35° altitude in the southeastern sky.

Through binoculars on Aug. 1, you'll find a star of similar brightness 0.4° to the planet's east. Neptune's motion carries it westward; on Aug. 31, the pair is 1° apart. A telescope will reveal the distant planet's dim bluish disk, spanning a mere 2". Neptune reaches opposition in September.

Jupiter lies in northwestern Cetus. It rises in the hour before midnight on Aug. 1 and soon before 9 P.M. local time by the 31st. It moves westward each night. Jupiter shines a brilliant magnitude –2.7 most of the month and reaches magnitude –2.8 in the last week of August.

The giant's apparent diameter spans 49" by late August. The best views are in the early morning hours, when the planet stands high in the southern sky. It lies due south at 53° altitude by 5 A.M. local time (an hour before sunrise) on Aug. 1, and by 3 A.M. on Aug. 31.

Small telescopes reveal parallel dark equatorial belts, while larger scopes show progressively more detail, tempered by local seeing conditions. The planet's temperate zones contain many spots, including the Great Red Spot that features every alternate night on average. All these features move quickly across the planet's face, carried by Jupiter's roughly 10-hour rotation period.

The four Galilean moons orbit Jupiter every two to 16 days. Dual transits are fascinating to follow; a fine example occurs Aug. 15/16. Less than an hour after Jupiter rises in the Midwest, Io's shadow begins a transit at 11:24 P.M. EDT. Io itself stands 19" east of the planet's limb at this time. Also spot Ganymede 36" east of Io — note this for later. Io is the innermost large moon and moves faster than more distant Ganymede. Beginning at 11:59 P.M. EDT, Ganymede's shadow appears

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (west)

MIDNIGHT
Mars (east)
Jupiter (east)
Saturn (south)
Uranus (east)
Neptune (southeast)

MORNING SKY
Venus (east)
Mars (southeast)
Jupiter (south)
Saturn (southwest)
Uranus (southeast)
Neptune (southwest)

COMET SEARCH | It's all about the dust

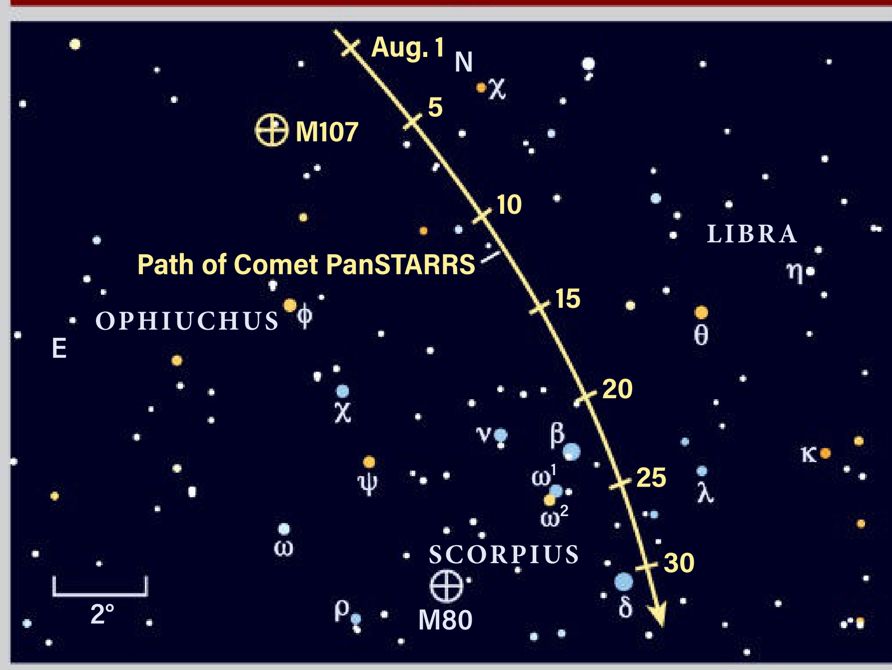
THE ENJOYMENT is set to continue as C/2017 K2 (PanSTARRS) glows at 7th magnitude. Catch it from the suburbs with a 4-inch scope or easily sweep it up with binoculars from a dark sky.

PanSTARRS starts August in Ophiuchus, about 2.5° northwest of 8th-magnitude M107 and 10.5° southwest of M10. All three targets are fairly compact and well defined, but the comet will be lopsided: very sharp on the southern flank where the solar wind hits and soft to the northeast as the dust spreads outward into a stubby fan.

For a comet some four times bigger than Halley, imagers might expect to capture the green glow from excited dicarbon molecules. But at a distance of 2.5 astronomical units (AU, where 1 AU is the average Earth-Sun distance), this mechanism won't have switched on. Comet dust reflecting our Sun's light will be neutral compared to the globulars, whose red giant stars give them a slightly warmer hue.

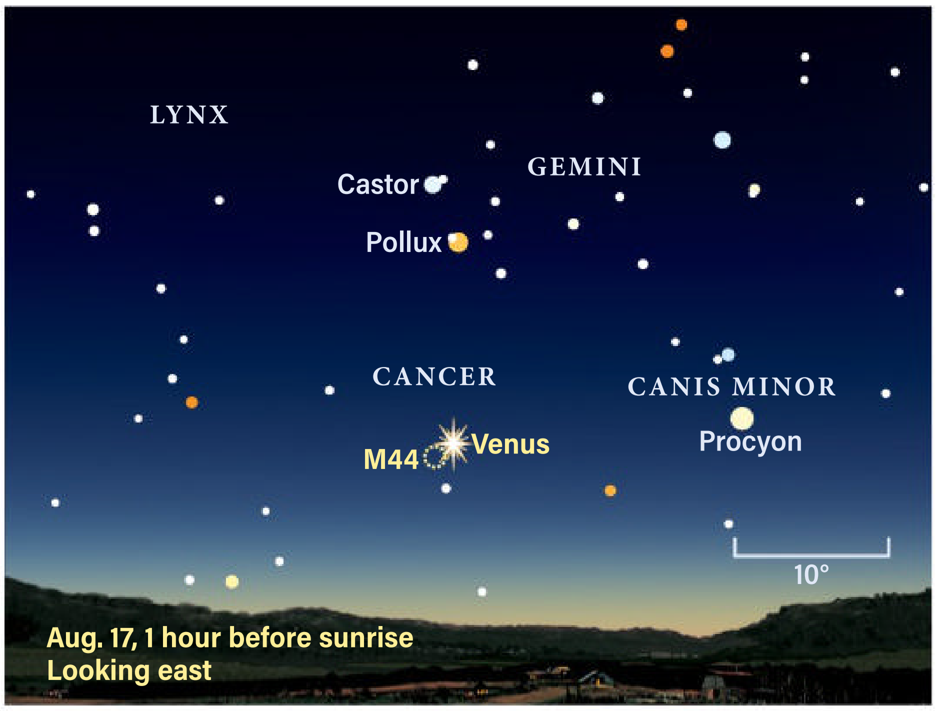
Later in the month, PanSTARRS slides through the beautiful binocular and telescopic fields of the Scorpion's face. Note the gorgeous wide double pair of Beta (β) and Omega (ω) Scorpii. Imagers with 135mm lenses can capture the comet along with the colorful Rho (ρ) Ophiuchi clouds to the east.

Comet C/2017 K2 (PanSTARRS)



Compare Comet PanSTARRS to globular clusters M10 (to the northeast, not shown) and M107. Which does it resemble more?

Morning stars



Venus sits near the Beehive open cluster (M44) the morning of Aug. 17. Center your binoculars on the bright morning star to enjoy the meetup.

southeast of Io's shadow. Now two shadows race across the jovian cloud tops, but faster Io's will stay well ahead. Io itself begins a transit 24 minutes later.

By 1 A.M. EDT (midnight CDT), Io has caught up with Ganymede's shadow and passes it within 30 minutes. Io's shadow departs the western limb of Jupiter at 1:38 A.M. EDT, followed just under an hour later by Io. Ganymede's huge shadow lingers until just before 3 A.M. EDT. If you stay up another few hours, you'll catch Ganymede itself beginning its transit at 4:09 A.M. EDT. It leaves by 5:39 A.M. CDT, just as twilight arrives in the Midwest.

Mars and **Uranus** rise together in Aries soon after midnight local time on Aug. 1. Mars is easy to find, shining at magnitude 0.2. Uranus is much fainter, requiring binoculars to spot at magnitude 5.8. Center Mars in your binoculars and you'll find Uranus 1.4° north of the Red Planet. Its bluish hue will contrast nicely with Mars.

Uranus has become the target of advanced imagers in recent years, and some elusive cloud features can be captured using high-speed video. Visually in a telescope, Uranus renders a 4"-wide featureless disk. A Last Quarter Moon ventures within 4° of Uranus the morning of Aug. 18.

Mars moves eastward and crosses into Taurus Aug. 9, while Uranus remains in Aries; already, 4.7° separate them. Mars treks 6° south of the Pleiades between Aug. 16 and 19. The 19th is also when the Last Quarter Moon catches up and lies less than 3° from Mars. In the predawn sky, telescopes might show the contrasting dark Syrtis Major and the bright Hellas basin on the tiny disk.

By Aug. 31, Mars stands 5.7° northwest of similarly orange-red Aldebaran, the brightest star in Taurus.

Mars season is now upon us: The Red Planet grows in apparent size from 8" to 10" during August. By the time it reaches opposition in December, Mars will be nearly double this size — smaller than recent years but the best for some time to come.

Venus is a brilliant morning star at magnitude –3.9 all month. On Aug. 1, it rises in Gemini two hours before the Sun. The planet crosses into Cancer on Aug. 10 and by Aug. 17 stands just under 1° west of the Beehive Cluster (M44). Look for the pairing in binoculars about 4° high one hour before sunrise.

Catch the waning crescent Moon 6.5° northwest of Venus Aug. 25 before sunrise. Venus' elongation from the Sun continues declining, reaching 14° by Aug. 31. Fortunately, its brilliance still renders it visible even in the bright dawn sky.

Through a telescope, Venus changes from a 93-percent-lit disk spanning 11" on Aug. 1 to 97 percent lit and 10" across on Aug. 31.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

LOCATING ASTEROIDS

Getting up there

HOW HIGH UP the asteroid list are you? 704 is the biggest number you'll see from the suburbs with a 4-inch scope, not counting the unusual near-Earth rocks. Floating in front of Pegasus' nose, main-belt asteroid Interamnia vaults up the southeastern sky.

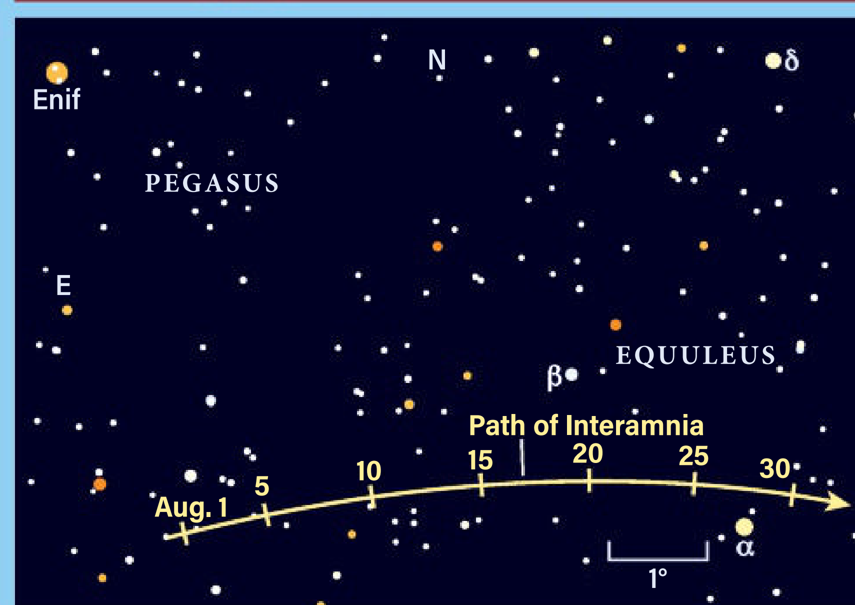
Use the bright star Enif (Epsilon [ε] Pegasi) to jump westward into Equuleus the Little Horse and land on magnitude 3.9 Alpha (α) Equulei, logically named Kitalpha. From the 23rd through the month's end, 200-mile-wide Interamnia lies within 1° of the star.

Before that, we can use the old-timer's trick of letting the sky drive for us. On Aug. 1, set your scope on Kitalpha, turn off any motors, and wait 23 minutes for Interamnia to come into view. By the 15th, it's down to an 11-minute drift. We can do this when both objects' declination is nearly the same.

Interestingly, 704 is the fifth-largest asteroid in the main belt! The reason it took so long to find is its high orbital inclination — 17° — which for long periods keeps it away from the ecliptic search zones. It's also darker than average and lies mostly outside the orbit of Ceres.

Interamnia is the Latin name for Teramo, Italy, where Vincenzo Cerulli built his observatory and later made his discovery in 1910.

Wild horses



Asteroid 704 Interamnia arcs through Pegasus and Equuleus, the Winged Horse and the Little Horse respectively, this month.


©M.Carroll

THE STRANGE CASE OF THE EYEBALL PLANETS

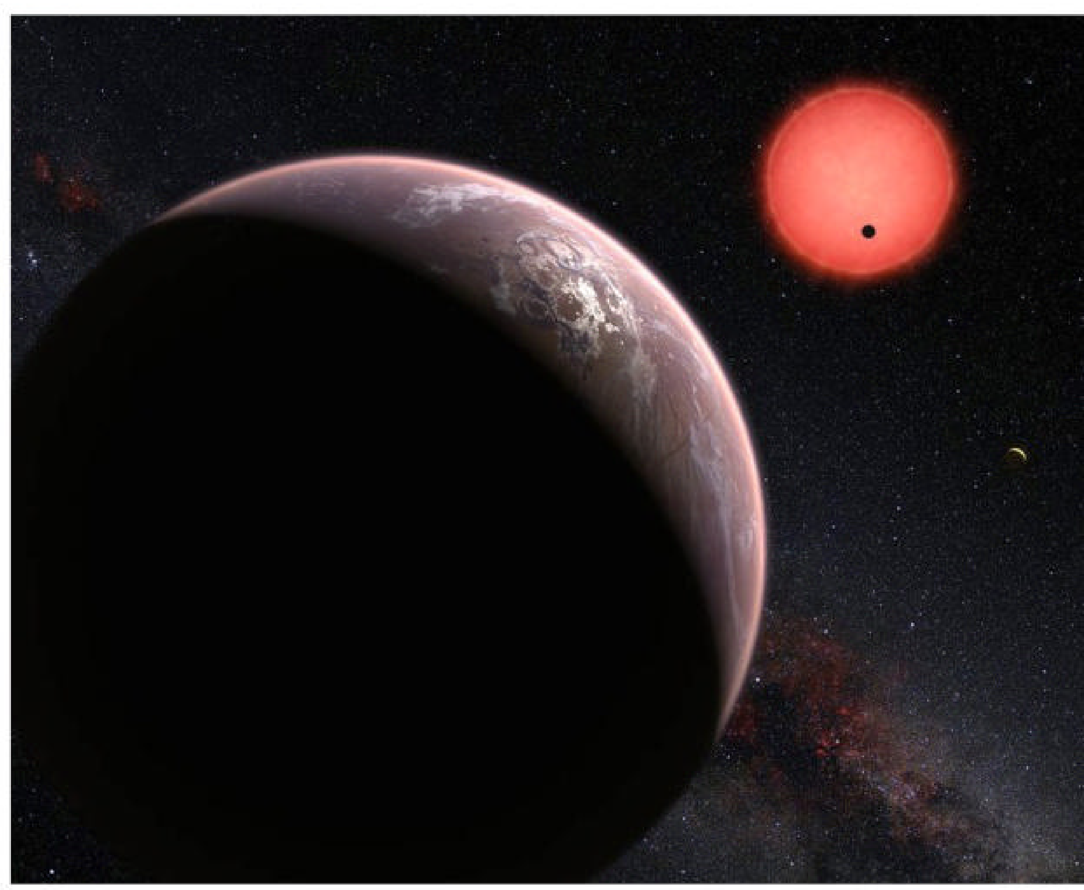
These tidally locked worlds could be the key to finding life in the universe — if they exist.

BY MICHAEL CARROLL

HUMANS HAVE LONG IMAGINED what life on another world may look like. And as we entered a golden age of exoplanet discovery, the hunt picked up for Earth 2.0, a twin to our planet orbiting within its star's habitable zone. But so far, searches have turned up empty, leading scientists to use some out-of-the-box thinking to find another haven for life in the universe.

The habitable zone, or Goldilocks zone, is the region surrounding a star where water can exist on the surface of an orbiting planet or moon. The hotter the star, the farther away its habitable zone sits. Take red dwarfs, for example: Of the hundreds of billions of stars in our galaxy, astronomers estimate that about 80 percent of them are red dwarfs. At a mere 0.08 to 0.5 times the mass of the Sun, these stars only reach surface temperatures around 4,000 to 6,700 degrees Fahrenheit (2,200 to 3,700 degrees Celsius). Thus, the habitable zone is quite close to these stars.

That proximity makes it much easier to spot any planets that pass in front of the tiny star, as such eclipses tend to block a large fraction of starlight and make the presence of an exoplanet clear. During its nine-year mission, the planet-hunting Kepler space telescope found 2,709 planets through this transit method; another 2,057 are still awaiting confirmation. And most of Kepler's finds are worlds circling close to red dwarf suns, some of which are similar in size to our own.



ABOVE: A tidally locked exoplanet orbits a red dwarf in this artist's concept. ESO/M. KORNMESSER/N. RISINGER (SKYSURVEY.ORG)

LEFT: Seen from a nearby moon, a tidally locked ocean world simmers beneath the light of its red dwarf sun. The sea along the terminator — the day/night boundary — freezes as it approaches the cold nightside, but temperatures at the point directly under the star may be quite temperate, with liquid oceans amenable to life. MICHAEL CARROLL

The TRAPPIST-1 system is home to seven Earth-like exoplanets. Of them, TRAPPIST-1 e (second from the right) is the most likely to host life, as it may have held onto any water on its surface. NASA/JPL-CALTECH

TRAPPIST-1 E

Distance from Earth: 41 light-years
Mass: 0.69 Earths
Radius: 0.92 times Earth
Year: 6.1 days

A member of one of the most famous stellar systems, TRAPPIST-1 e is one of seven exoplanets around Trappist-1. Several of the worlds may be eyeball planets. But while all the planets could also have water, only three lie firmly within the star's habitable zone.

A hot, bright, early stellar phase may have caused all the evolving planets to look like Venus: any early oceans long since evaporated, leaving behind a thick, uninhabitable atmosphere. But according to a 2018 study published in the *Astrophysical Journal,* Trappist-1 e is the most likely to have managed to retain water, perhaps even hosting an Earth-like ocean.

All seven of the Trappist-1 planets have similar densities, making the system very different from our own. Such similar densities suggest the planets also all have similar compositions. The James Webb Space Telescope will be able to probe further into the atmospheres of these exoplanets, searching for elements that could hint at the presence of life.

Among these Earth-like exoplanets, there exists a bizarre class known as eyeball planets. These worlds orbit so near to their suns that they are tidally locked, with one hemisphere always facing toward the star and the opposite one in eternal night. Scientists are beginning to realize that eyeball worlds are more than just curiosities — they're key to understanding how common life might be in the universe. Their arrangement of an always-lit and always-dark side causes fascinating weather and unusual surface conditions. These characteristics may make eyeball planets within the Goldilocks zone prime candidates for hosting life, but they could also make otherwise habitable planets inhospitable.

OCEANIC EYES

After coalescing around its star, a planet has some spin. But over time, the host star's gravity pulls at the world, slowing the body's rotation until it becomes tidally locked. We have a good example of such synchronous rotation on our own cosmic front porch: The Moon orbits Earth once a month and takes the same amount of time to turn once on its axis. This means that we always see the same face of our Moon.

Eyeball planets initially got their moniker when astronomers noted that in the habitable zone, tidally locked worlds covered by water would become frozen starting at the terminator (the edge of night) while the seas would remain clear near the substellar point (the point that directly faces the star).

This dark blue central ocean surrounded by sea ice gives the appearance of an eyeball.

As astronomers racked up exoplanet discoveries over the last 30 years, they realized eyeball planets may be plentiful among planetary systems and that a wide range of worlds may take on an eyeball form. One common example is super-Earths, worlds that are larger than Earth but smaller than Neptune.

Allison Youngblood, an astrophysicist at NASA's Goddard Space Flight Center in Greenbelt, Maryland, has been using the Hubble Space Telescope to study super-Earths orbiting near red dwarfs. "There's some evidence of super-Earths with thick atmospheres and some with thin or no atmospheres at all," but observations point to many of these worlds being "really cloudy and hazy," she says. This would make spotting life difficult, but some astronomers believe that, in the right scenario, super-Earths hold the most promise for life beyond the solar system.

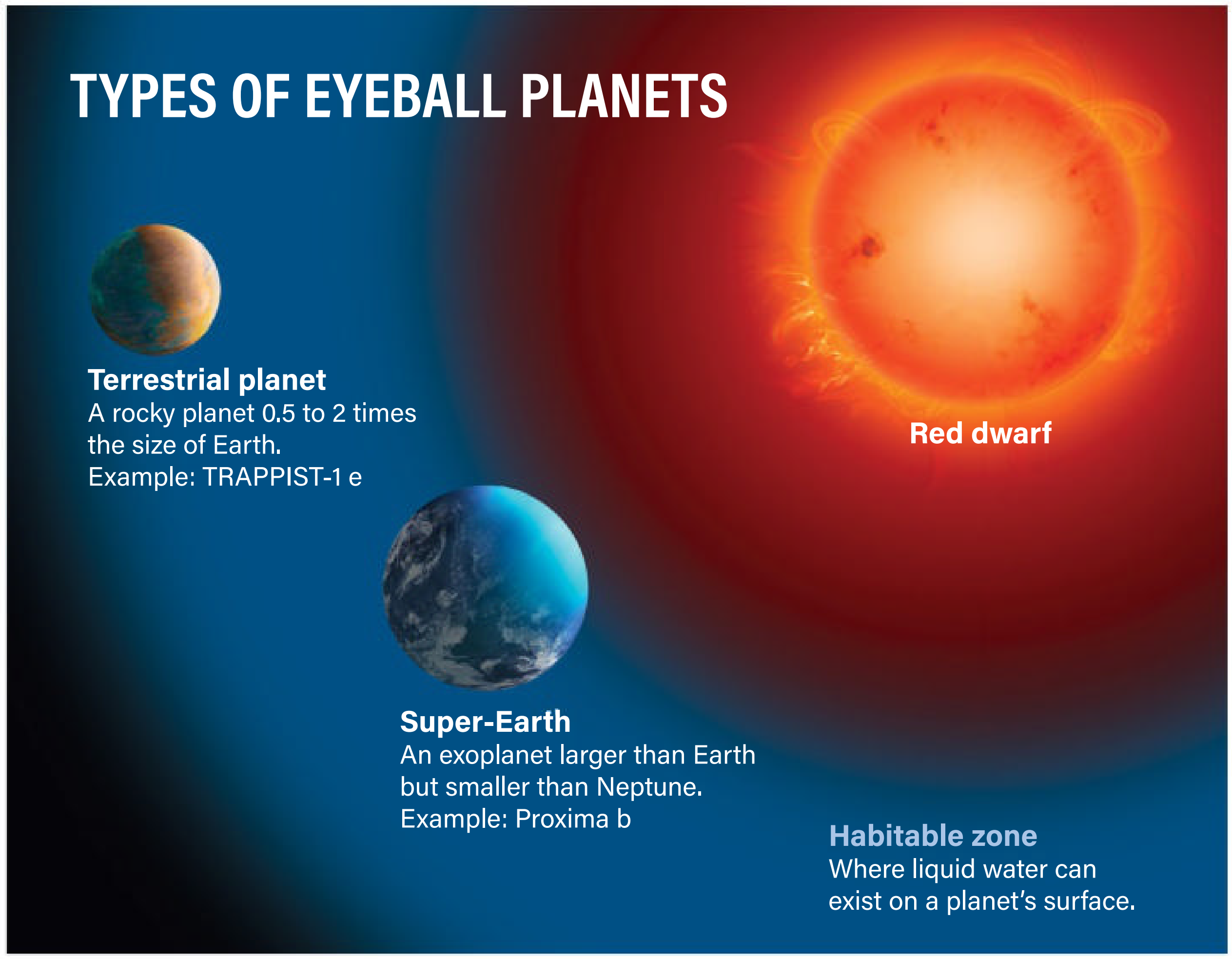
One such scenario is on eyeball super-Earths. These worlds are likely covered in vast oceans. On the night hemisphere, the planet suffers arctic conditions while the dayside swelters, the heat burning away clouds and, in extreme scenarios, the ocean itself. The habitability of such a planet depends on a lot of factors, including the day/night temperature, the activity of the host star, the density of the planet's atmosphere, and even the saltiness of the ocean.

As it so happens, a prime target for habitability sits just at our interstellar back door. Proxima b is an eyeball super-Earth orbiting within the habitable zone of Proxima Centauri, the closest star to our solar system. A 2017 study published in *Astrobiology* modeled potential climates of the exoplanet, assuming a variety of conditions. The researchers concluded that a Proxima b "with an atmosphere similar to modern Earth's can have a habitable climate with a broad region of open ocean, extending to the nightside."

How far the ocean extends depends upon the amount of salt assumed in the water, but even with an ocean with high salinity, Proxima b could theoretically host life. One only has to look as far as Earth's infamous Dead Sea, where life has found a way to thrive despite a salt concentration above 30 percent. So, it isn't impossible for salt-loving bacteria to likewise exist on Proxima b in this scenario.

Open oceans aren't the only possible surface conditions for Proxima b. A paper published in *Nature Astronomy* in 2019 suggests that oceans beneath the substellar point might freeze over because of sea-ice dynamics. Modeling conditions on Proxima b, the researchers found that as sea ice drifts into warmer waters, the ice cools the ocean as it melts. Gradually, more and more of the ocean freezes, even on the dayside. At that point, only an atmosphere with abundant greenhouse gases could prevent global freezeover.

But, according to Eric Wolf, a research associate at the Laboratory for Atmospheric and Space Physics in Boulder, Colorado, other models have shown the opposite scenario. Just as ice can drift from cold regions to warm regions, heated waters can also serve as



ASTRONOMY: ROEN KELLY

On smaller eyeball planets, desert conditions likely reign supreme on the dayside, while the nightside of the world freezes. The terminator may be a haven for potential life, as liquid water could exist there. ESO/L. CALÇADA

On an ocean-covered eyeball planet, there may lie a region near the terminator where the icy nightside gives way to liquid water. NASA/JPL-CALTECH/T. PYLE (IPAC)

a transporter of heat from warm regions to cold regions and melt the ice, warming the climate instead. "Depending on the details," Wolf says, "the climate could very literally be anything from the cold, icy states shown by [the 2019 study] to Venus-like, hot, CO_2-dominated worlds, or they could even look like [Saturn's moon] Titan with [methane] and hazes." Not to mention that if continents are included in the mix, he adds, "all bets are off because the presence and location of continents significantly changes the patterns of ocean transports."

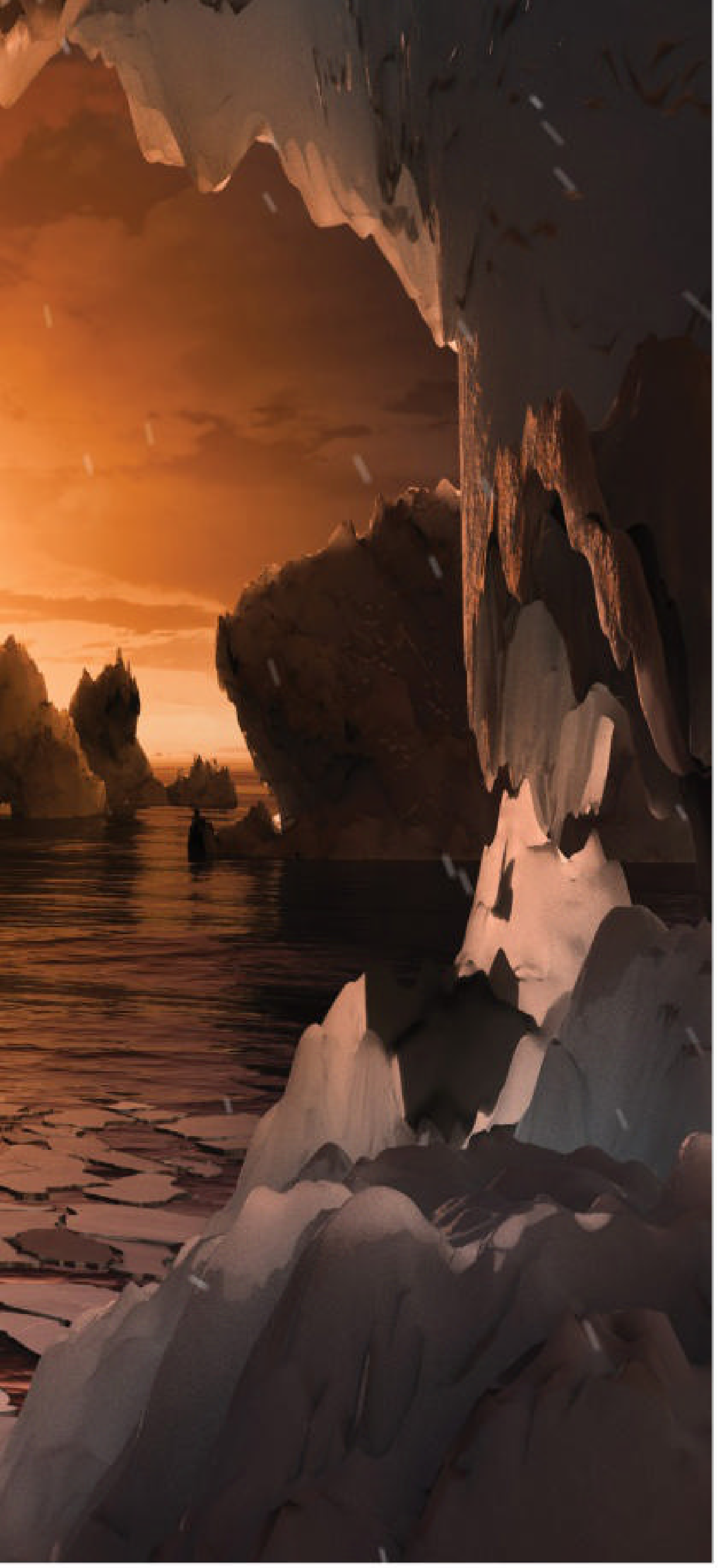
So even if an eyeball planet lies within the habitable zone, its surface can range wildly from endless ocean to frozen wasteland.

EVEN IF AN EYEBALL PLANET LIES WITHIN THE HABITABLE ZONE, ITS SURFACE CAN RANGE WILDLY FROM ENDLESS OCEAN TO FROZEN WASTELAND.

ROCK-SOLID PLACES

While super-Earth eyeball planets are ocean-covered orbs cocooned in dense atmospheres, smaller Earth-like tidally locked worlds have rockier surfaces. Where the planet's star blazes overhead, desert conditions blanket the landscape. Closer to the nightside, the environment becomes more clement, perhaps allowing for liquid water within that twilight zone. Also within that twilight region, provided the planet has enough atmosphere with strong wind currents, the surface may remain above freezing. But if the air is thin or stagnant, temperatures will drop precipitously, even if the planet is on the inner edge of its star's habitable zone.

However, these smaller eyeball planets face a larger problem than temperature in terms of habitability: atmospheric erosion. An atmosphere is crucial for life's survival, but, orbiting close to their red dwarf suns, these small worlds face ferocious stellar winds that can strip away even the densest of atmospheres.



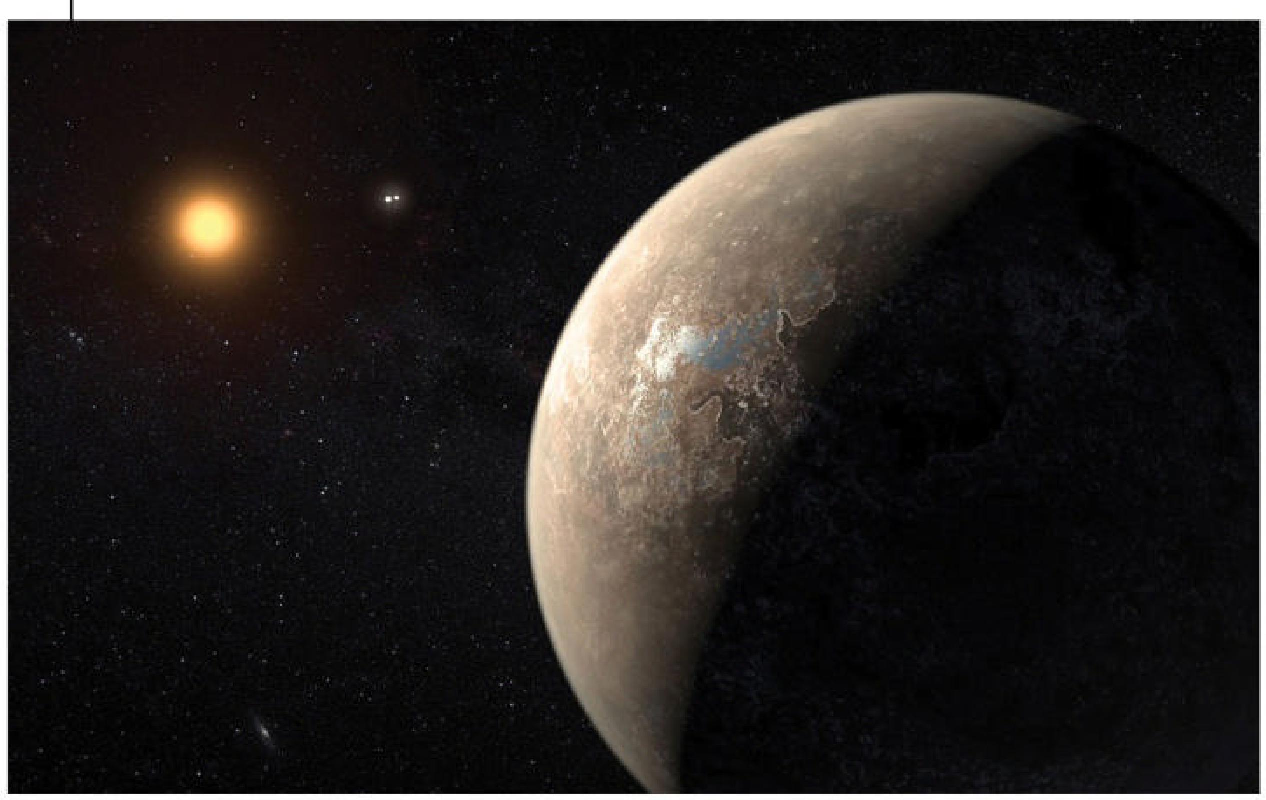
PROXIMA CENTAURI B

Distance from Earth: 4.2 light-years
Mass: 1.27 Earths
Radius: estimated 1.08 times Earth
Year: 11.2 days

Proxima Centauri b — often shortened to just Proxima b — is a super-Earth discovered through the subtle wobble of Proxima Centauri itself. As the star is pulled toward and away from us by its unseen planet, its light shifts toward the blue and then the red end of the spectrum, respectively. Proxima Centauri is also home to two other planets.

Likely a large terrestrial world, Proxima b is within its star's habitable zone. But the planet probably receives bouts of ultraviolet radiation hundreds of times greater than that Earth receives from the Sun. This radiation may have stripped away Proxima b's atmosphere.

Even if Proxima b does have an atmosphere, it's difficult to model the planet's surface because scientists don't know its radius. Most exoplanets have been found using the transit method — when the world happens to pass in front of its star. This technique also allows researchers to measure an exoplanet's radius. But Proxima b is not known to transit, so its radius is unknown.



Astronomers recently discovered that Proxima Centauri is home to three exoplanets. Proxima b, the innermost world, is a super-Earth, but likely receives too much radiation to host life. ESO

Exoplanet expert Avi Mandell of NASA's Goddard Space Flight Center points out that "some amount of atmosphere will always be eroded — we're losing some atmosphere from Earth all the time due to our own Sun." But, if not replenished quickly enough by gases leaking out from the planet's interior, an atmosphere may lose the compounds that are needed to sustain life, or simply evaporate entirely.

Youngblood suggests that the amount of atmospheric loss will depend on what kind of atmospheric escape is occurring. The most troublesome escape is known as hydrodynamic escape. Today, only a handful of different atoms are escaping Earth from the top of the atmosphere. But in the case of hydrodynamic escape, that trickle becomes a gush, with escaping atoms acting like a fluid that drags still-heavier atoms and molecules along for the ride. Ultimately this kind of atmospheric escape is driven by heat and, once a planet reaches this point, there is no stopping the erosion. Researchers think this phenomenon could explain planetary atmospheres that appear mysteriously drained of oxygen, nitrogen, and heavier noble gases.

But there are ways around this runaway loss, giving life on small eyeball planets a lifeline. It's likely that both Venus and Earth saw hydrodynamic escape early in their evolution, yet they have managed to retain thick

atmospheres today. According to Youngblood, mitigating the atmospheric erosion "partly depends on the composition of the atmosphere — what atoms or molecules are present high in the atmosphere that absorb the stellar radiation that drives escape."

An example of what various atmospheric conditions can look like on a small eyeball world lies a mere 40 light-years away. The TRAPPIST-1 system is famed for hosting seven Earth-like exoplanets. Of them, TRAPPIST-1 e is a small eyeball world and the most likely to be suitable for humanlike life, according to a 2017 study published in *The Astrophysical Journal Letters*.

The study modeled what the world may look like under a variety of atmospheric conditions. Without greenhouse gases, TRAPPIST-1 e would be a cold world, but, even with just a thin atmosphere, the world could remain habitable at the substellar point. Conditions warm if the planet is home to an Earth-like atmosphere, but become inhospitable relatively quickly as more carbon dioxide is injected into the modeled atmosphere.

Therefore, even atmospherically challenged eyeball exoplanets could contain regions of habitability under the right conditions.

JWST: THE OPHTHALMOSCOPE

Eyeball experts now have a new tool: the James Webb Space Telescope (JWST). Outer planets researcher Heidi Hammel, a member of the JWST team, looks forward to new revelations from the powerful observatory. "Webb's strength is in atmospheric chemistry; it will be complementary to what the Hubble Space Telescope is doing," she says. Hubble sees from the ultraviolet to near-infrared, but Webb is sensitive to a different part of the infrared.

Already, researchers plan to use JWST to observe several eyeball planet candidates. In some cases, Webb will watch a planet as it transits its star. When a world moves in front of its star, it's possible to not only spot the planet, but also determine what molecules exist in its atmosphere. Just as the planet blocks starlight with its solid surface, so too can the molecules in the atmosphere absorb light from the planet's sun, creating dips in the spectrum of light we receive from the star. Studying these missing wavelengths of starlight can give scientists insight into the chemical composition of the planet's atmosphere.

In other cases, JWST will observe a planet as it passes behind its star, an effective technique for measuring how much of the system's total light is reflected by the dayside of the planet. This can give researchers insight into both the chemical composition of a world and its temperature.

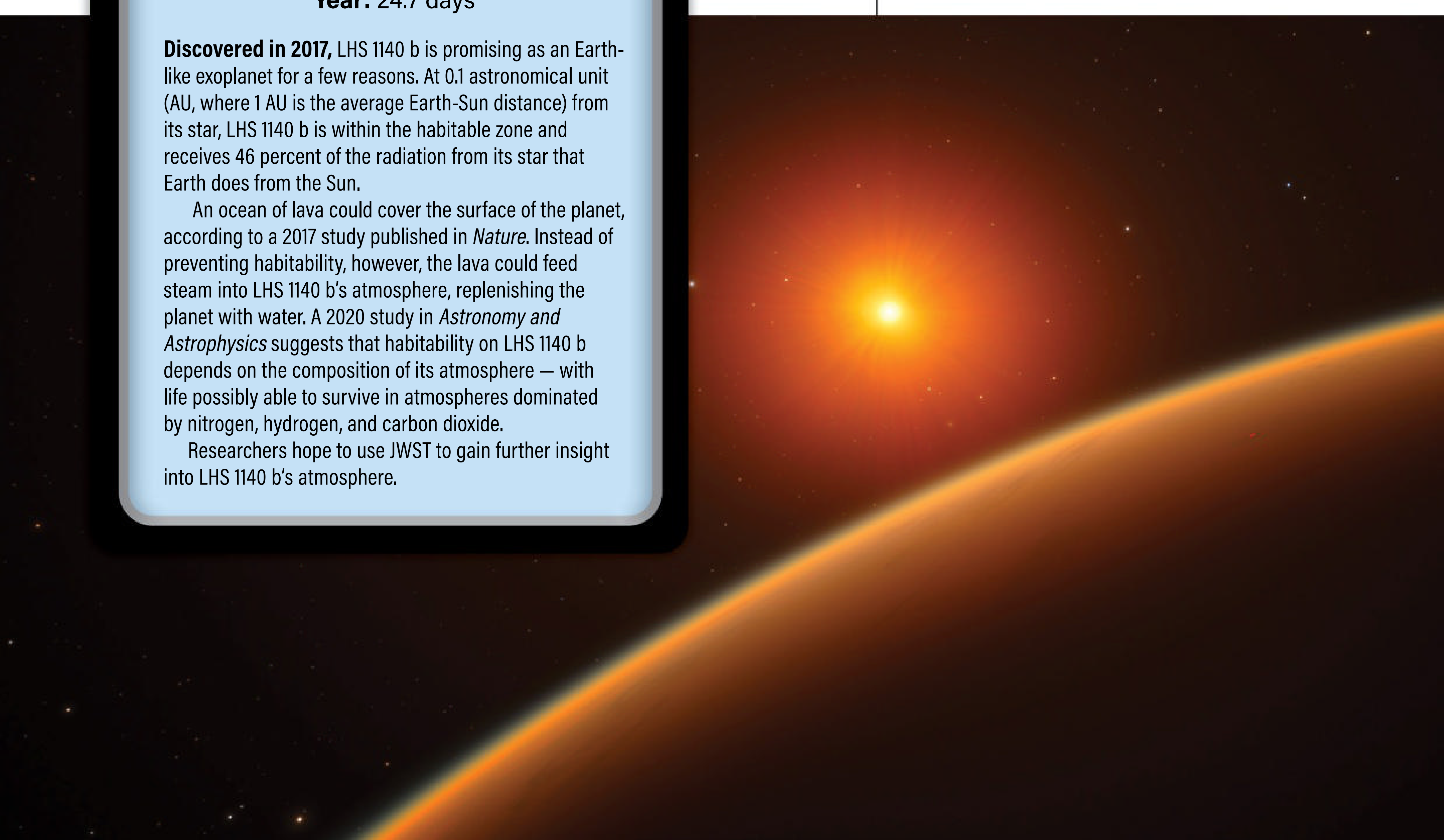
LHS 1140 B

Distance from Earth: 48.8 light-years
Mass: 6.4 Earths
Radius: 1.6 times Earth
Year: 24.7 days

Discovered in 2017, LHS 1140 b is promising as an Earth-like exoplanet for a few reasons. At 0.1 astronomical unit (AU, where 1 AU is the average Earth-Sun distance) from its star, LHS 1140 b is within the habitable zone and receives 46 percent of the radiation from its star that Earth does from the Sun.

An ocean of lava could cover the surface of the planet, according to a 2017 study published in *Nature*. Instead of preventing habitability, however, the lava could feed steam into LHS 1140 b's atmosphere, replenishing the planet with water. A 2020 study in *Astronomy and Astrophysics* suggests that habitability on LHS 1140 b depends on the composition of its atmosphere — with life possibly able to survive in atmospheres dominated by nitrogen, hydrogen, and carbon dioxide.

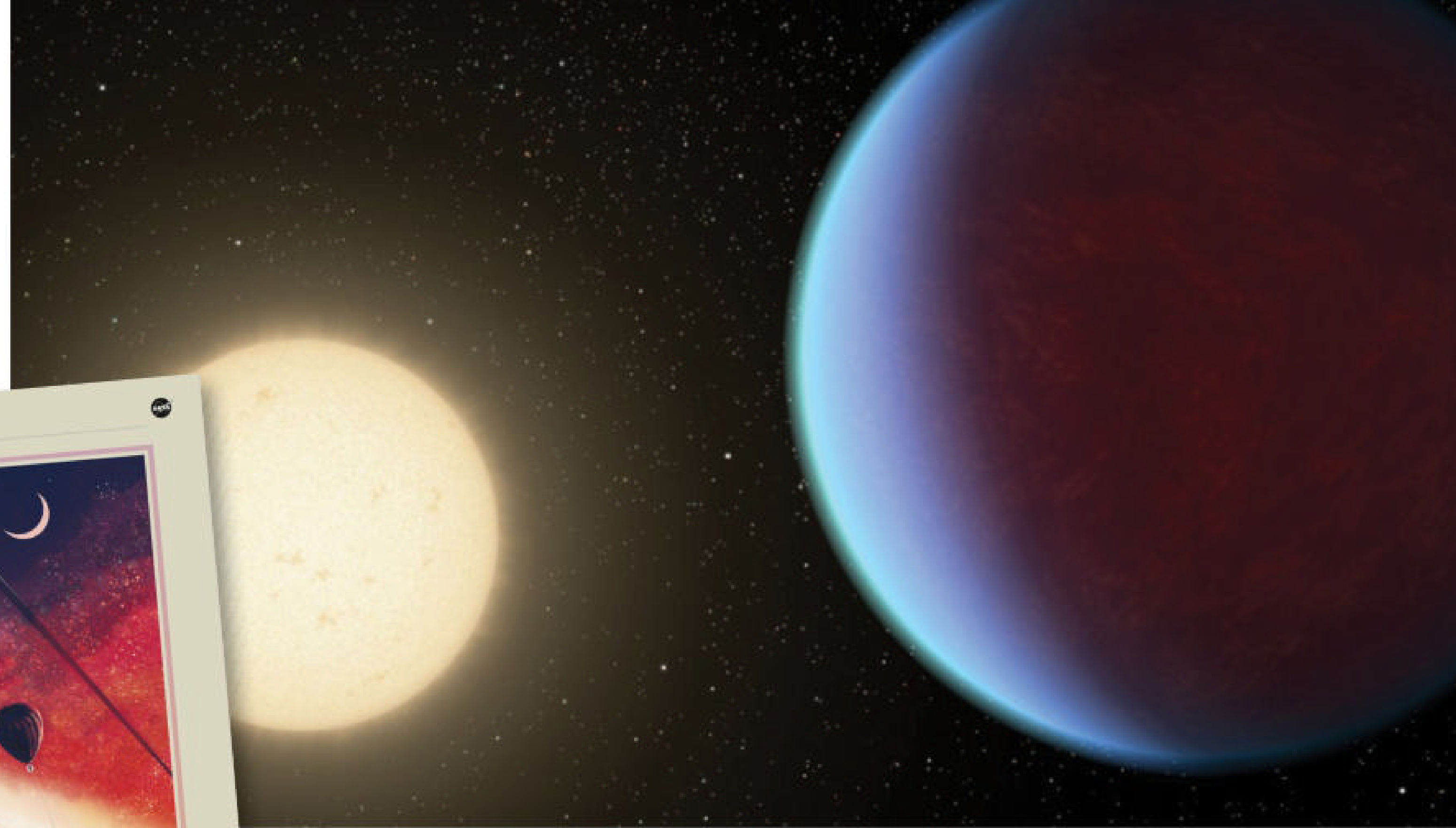
Researchers hope to use JWST to gain further insight into LHS 1140 b's atmosphere.



BELOW: Some 40 light-years from Earth lies LHS 1140 b. In 2020, the Hubble Space Telescope spied potential evidence of water in this eyeball world's spectrum. ESO/SPACEENGINE.ORG

RIGHT: 55 Cancri e likely has an atmosphere thicker than our own, hiding its lava-covered surface from our view. NASA-JPL/CALTECH

BELOW: Tidally locked to its star, 55 Cancri e promises visitors an ocean of lava. NASA-JPL/CALTECH

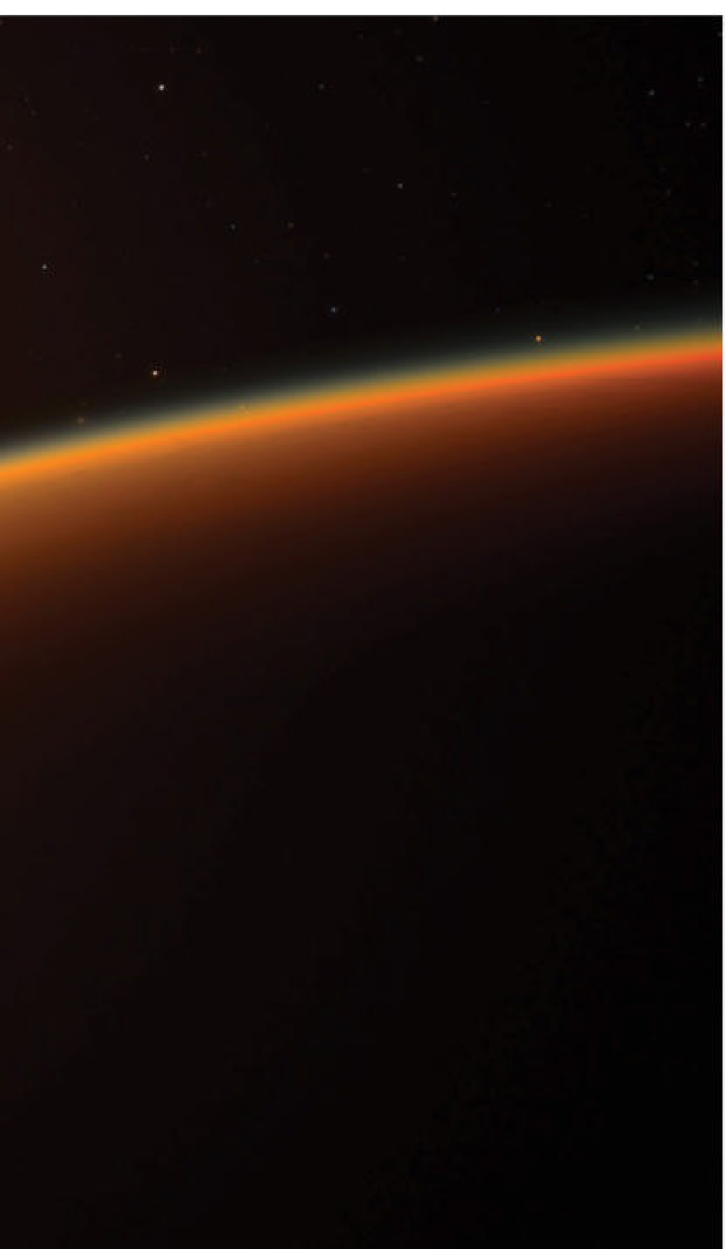


55 CANCRI E

Distance from Earth: 41 light-years
Mass: 7.99 Earths
Radius: 1.9 times Earth
Year: 0.7 day

Orbiting a star called Copernicus (also known as 55 Cancri A, or just 55 Cancri), 55 Cancri e is uninhabitable, thanks to a molten surface with a temperate greater than 3,000 degrees Fahrenheit (1,600 degrees Celsius).

When the planet was first discovered, researchers suggested that its host star's high ratio of carbon to oxygen could indicate 55 Cancri e was covered in a thick layer of diamond. But further analysis showed that Copernicus contains more oxygen than carbon after all, eliminating this fanciful possibility.



Currently, climate models can vary widely as scientists move beyond the strict Earth-centric models they've used in the past. Adding new data from JWST, scientists will be able to put further constraints on the atmospheric models that can be applied to an eyeball planet, giving them a better idea of what conditions may exist on its surface.

Already, JWST is slated to study many eyeball planets that Hammel calls "the usual suspects." She says, "Any of the exoplanet systems that you can name are targets for Webb — like the TRAPPIST planets or 55 Cancri e — so there are about 68 exoplanets on the list, including five or six terrestrials in habitable zones." And some of them are eyeball planets.

While conditions would be different than Earth, alien life could exist beneath such exotic skies. And they could see a plethora of landscapes: frozen wastelands, rugged mountains, parched deserts, or oceans from horizon to horizon. Only time will tell what strange and wondrous forms life could take under the angry glare of a red dwarf sun.

Michael Carroll *is a writer, lecturer, and artist. He has published over 30 books in print. His latest novel is* Plato's Labyrinth: Dinosaurs, Ancient Greeks, and Time Travelers *(Springer, 2021).*

Capturing the MOON in high res

The digital revolution has enabled amateur astronomers to take crisp, clear images that would have been the envy of professionals just a few decades ago.

BY LEO AERTS AND KLAUS BRASCH

Few technological advances have impacted astronomy as much as the digital revolution. That's been true in the professional realm since the 1980s, and it's been true for amateur astrophotographers like us since the turn of the millennium. Perhaps nothing illustrates this seismic shift more vividly than comparing historic photographs of the Moon with their more modern counterparts.

For instance, take the great lunar crater Clavius, imaged in the 1950s with what was then the world's largest telescope, the 200-inch Hale telescope at Palomar Observatory. If you compare that shot (see the top of page 51) with a corresponding image taken in 2005 using a standard 14-inch consumer scope and one of the first commercially available CCD cameras, the differences in resolution, sharpness, and dynamic range between the two are striking.

So, what are some of the tools and methods for cutting-edge lunar imaging now available to those with telescopes suitable for amateurs (6 to 14 inches)? Apart from good optics and a solid mount, most practitioners can employ any number of excellent webcam models or laptop computers (with appropriate image-capture software), as well as sophisticated image-stacking and processing software. In addition, for close-up, high-resolution imaging of select lunar features, quality Barlow lenses or Powermates — which both extend focal lengths — are essential, as are atmospheric dispersion correctors and, typically, near-infrared filters to minimize the effects of less-than-perfect seeing conditions.

Shooting from his home near Brussels, Belgium, one of this article's authors, Leo Aerts, routinely uses a custom-built Opticon 10-inch f/15 "planetary" Schmidt-Cassegrain (with only a 25 percent central obstruction) and a Celestron 14-inch f/11 scope, both on movable Losmandy G-11 equatorial mounts. The telescopes are stored in his home garage and wrapped in thermal insulating material to prevent overheating during daytime hours.

Although Aerts has used many older model webcams, including several DMK CCD models, they operated at relatively low capture rates of 30 to 60 frames per second (fps). His current favorite cameras are ZWO CMOS models, an ASI 178MM with a 2.4 micrometer (µm) pixel size, and an ASI 290MM with 2.9 µm pixels. These models perform very well up to 150 to 250 fps, with low levels of noise and high infrared sensitivity. Aerts also routinely uses an AstroTechniek atmospheric dispersion corrector, especially when his target is below 40° high in the humid Belgian skies. These handy optical devices have two rotatable prisms made of silicate glass, which can be adjusted to introduce a degree of native chromatic aberration that counteracts that of our atmosphere.

So, what are some of the tools and methods for cutting-edge lunar imaging now available to those with telescopes suitable for amateurs?

In short, a typical imaging run for Aerts varies depending on his webcam's field of view and seeing conditions. He'll collect anywhere between 4,000 and 5,000 frames for a full shot of the Moon and 15,000 to 20,000 frames for a close-up of a lunar region of interest. Of those, about 800 to 900 of the best frames are combined with his preferred stacking software, AutoStakkert. If seeing conditions are excellent, he caps the number of selected frames at about 10 percent of the total shot, provided the noise level allows it. Aerts uses FireCapture for image capture and

Author Leo Aerts' optically superb telescope, an Opticon 10-inch f/15 "planetary" Schmidt-Cassegrain, is shown at left. Above, Aerts and his full setup are ready for an exciting imaging session in his backyard. ALL IMAGES BY LEO AERTS UNLESS OTHERWISE NOTED

Photoshop 10 for final processing. Any refining or elimination of noise levels is done with the unsharp masking application or the wavelets function of Astra Image.

One common misstep for new imagers is not monitoring seeing conditions throughout observing. During an extended imaging run, conditions can vary considerably, which can ruin a good portion of your session. Limit your image capture to periods of favorable seeing, pausing when necessary, and only resuming once seeing stabilizes again. It may be overwhelming at first, but, as with any new endeavor, consistency, patience, and persistence are essential.

Digital technology has reached a level of precision that allows amateur practitioners to generate pictures rivaling those produced by early space probes, and even some of the lower-resolution images taken by NASA's Lunar Reconnaissance Orbiter (LRO). To bring that point home, we have put together a sort of virtual tour of the lunar landscape, featuring some of its highlights, as well as the more captivating aspects of familiar regions across the Moon's spectacular surface. Except where otherwise indicated, all images were taken by Aerts with a standard 14-inch Celestron.

Who among us hasn't imagined what an incredible experience it must have been for the Apollo astronauts to approach and circle the Moon just a few miles above its surface?

Flying over the Moon

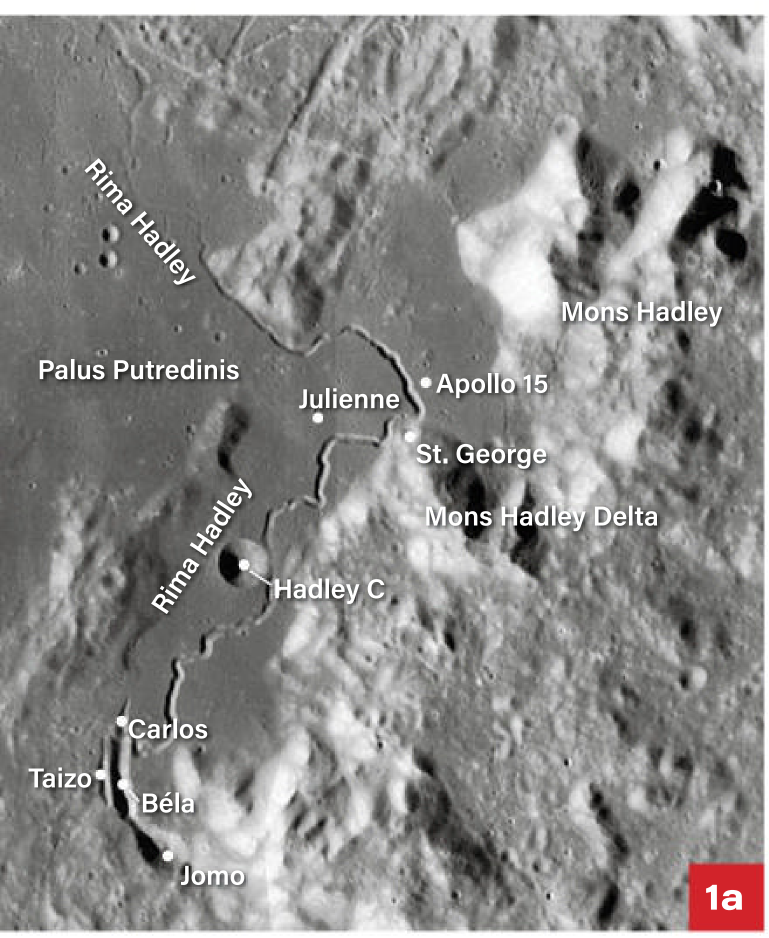
Who among us hasn't imagined what an incredible experience it must have been for the Apollo astronauts to approach and circle the Moon just a few miles above its surface? Seeing that otherworldly panorama of craters, mountains, smooth lava plains, and endless horizons in brilliant detail must have been an incomparable adventure. And while few of us are likely to experience that in person, we can accomplish it virtually thanks to the magic of digital imaging.

The first stop on our lunar tour is the path of one of the most scientifically productive Apollo missions: Apollo 15. In 1971, the astronauts landed in the Hadley–Apennine region near the Montes Apenninus (Apennine Mountains), in the northern hemisphere of the Moon bordering Mare Imbrium (Sea of Rains). Their assignment was to investigate and collect samples in the area around Rima Hadley (Hadley Rille), a volcanic channel likely formed during the Moon's early history. To accomplish this, David Scott and James Irwin were equipped with the first Lunar Roving Vehicle, allowing them to roam and explore a sizeable area near their landing site.

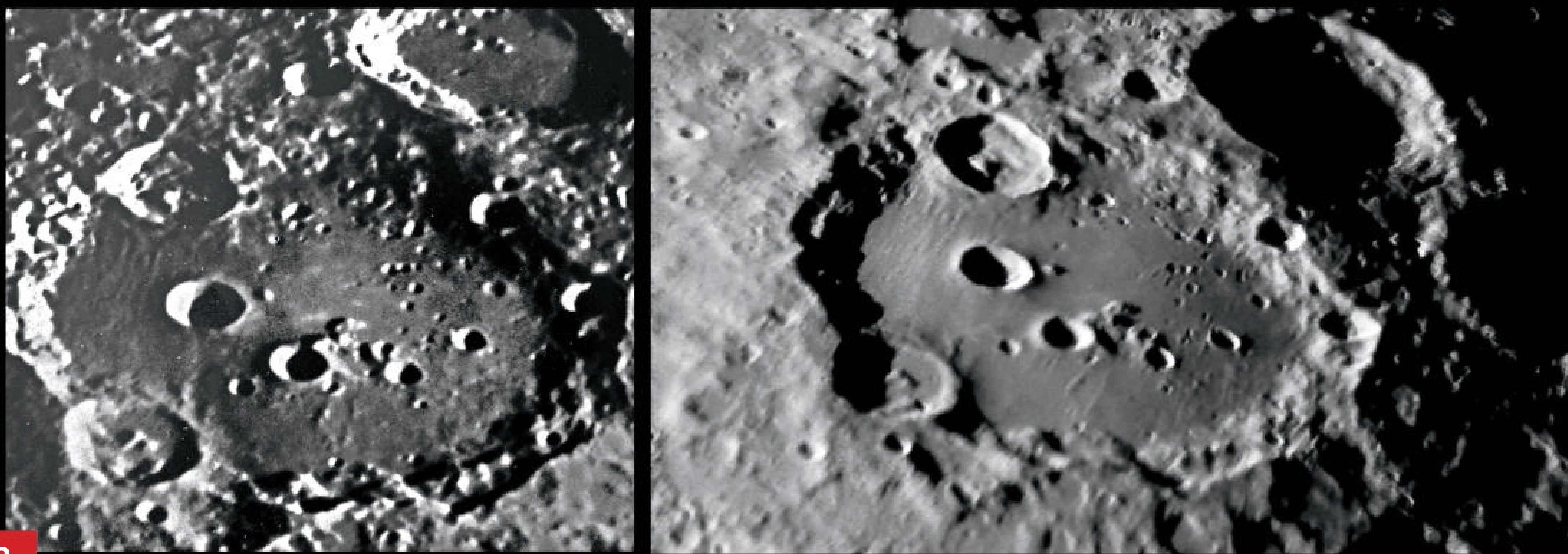
With consumer equipment, the snaking valley of Rima Hadley, only roughly 1 mile (1.6 kilometers) wide, is easily visible, as well as both Mons Hadley and Mons Hadley Delta, the massive mountains that surround their landing site.

Chasing shadows

One of the most absorbing activities seasoned observers can undertake is following the gradual changes in the shadow patterns of selective



1A AND 1B The Apollo 15 landing site and nearby features are shown in this photo of the Hadley-Apennine site taken from lunar orbit (1a). A similar-scale shot taken Aug. 24, 2016, with a Celestron-14 reveals even finer detail (1b). LEFT: NASA/JSC/ARIZONA STATE UNIVERSITY



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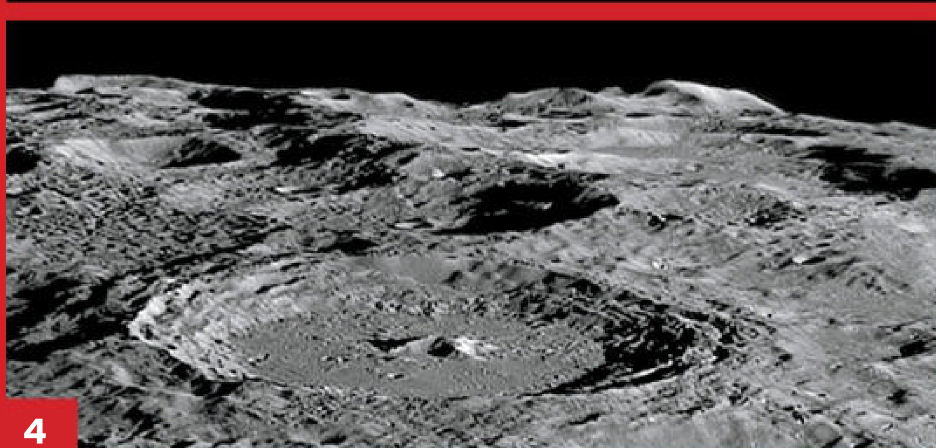
2 The splendid lunar crater Clavius was imaged in 1953 with the 200-inch Hale telescope (left) and in 2005 with a Celestron 14-inch Schmidt-Cassegrain consumer scope and an early model Nikon Coolpix 3.3-megapixel CCD camera (right). LEFT: PALOMAR OBSERVATORY

3 Showing some of the Moon's major craters, including Schomberger at lower left, this detailed limb view of the lunar south pole taken July 2, 2017, captures how it might appear to passengers during a flyover.

4 The imposing Leibnitz Mountains, located near the lunar south pole, are visible behind the striking crater Moretus in the foreground in this shot taken during a favorable libration in August 2016.

5 The remarkable system of rilles (long, narrow lunar valleys) running down the western portion of Mare Tranquilitatis (Sea of Tranquility) pop into view in this shot taken along the terminator (the dividing line between lunar day and night) on May 27, 2020.

3



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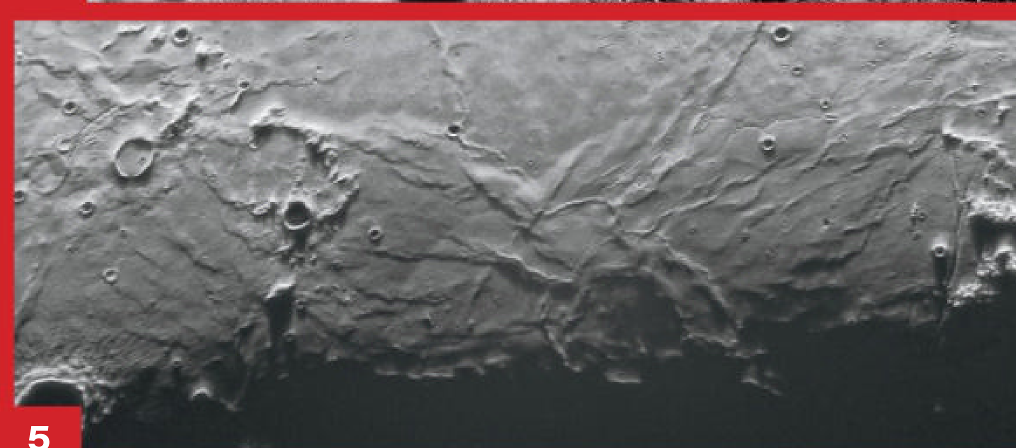

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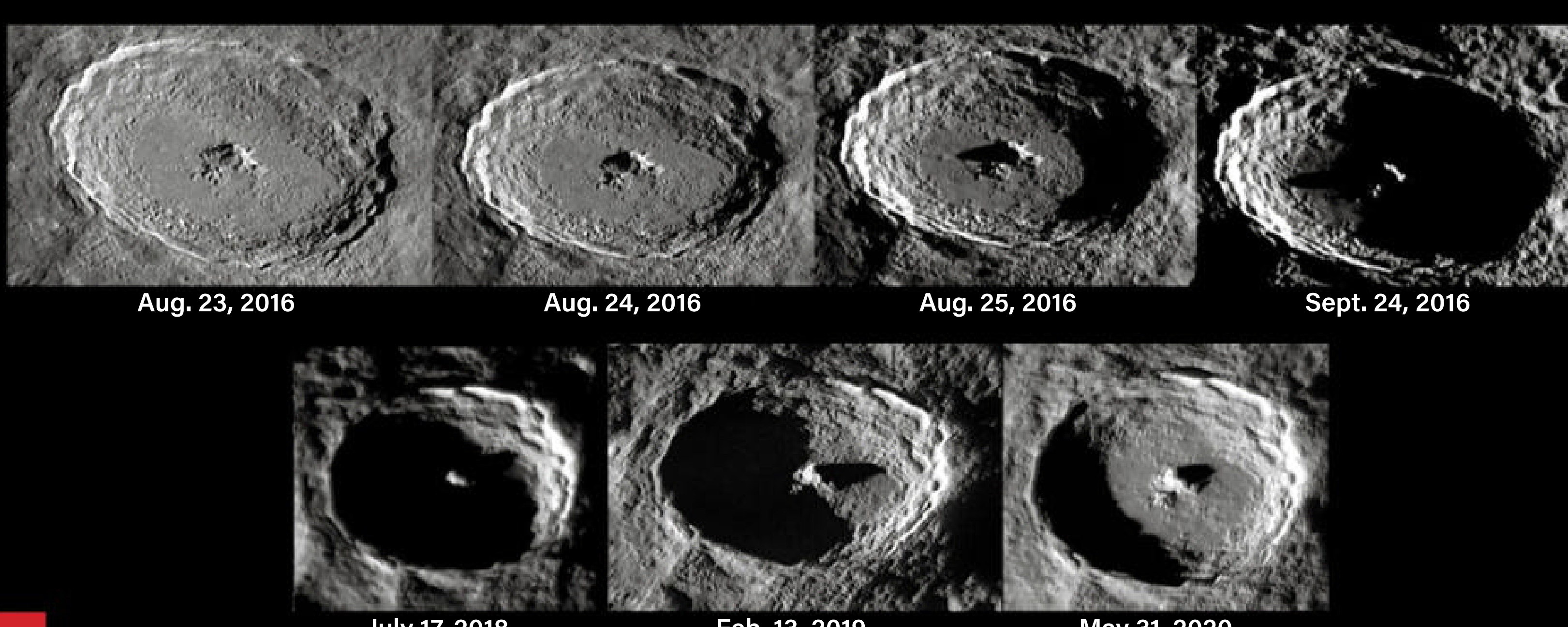

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6 Progressing shadows on Tycho Crater provide patient observers with a variety of captivating views. The images in this series were all taken with a 10-inch Opticon Schmidt-Cassegrain telescope.

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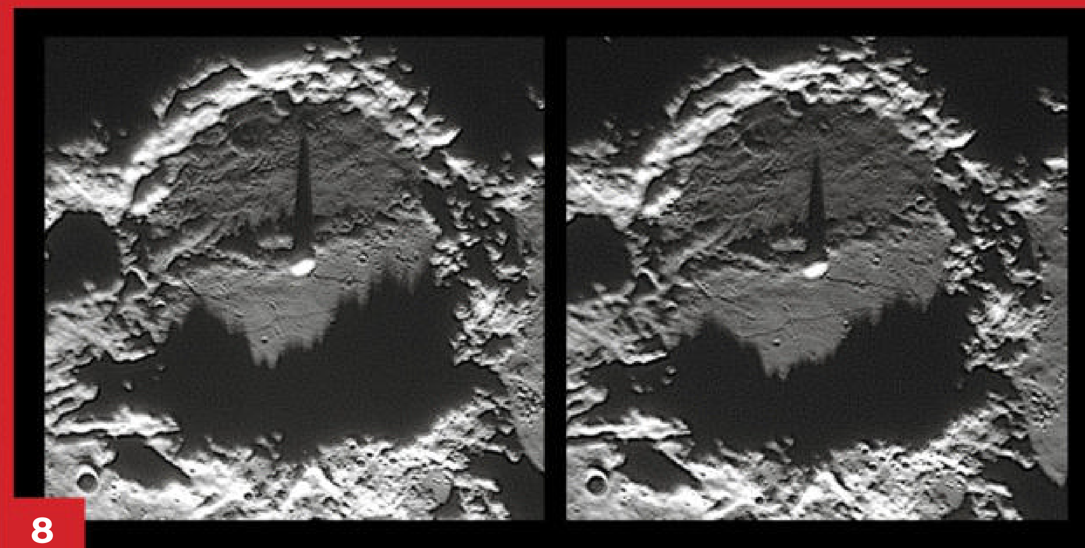

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7 Evolving illumination reveals features within craters (from top) Ptolemaeus, Alphonsus, and Arzachel in these shots taken May 12, 2019; Feb. 12, 2019; and March 24, 2018, respectively.

8 Thanks to grazing light conditions Feb. 12, 2019, the shadows cast by crater Alphonsus and its prominent central peak evolve over a period of just 48 minutes.

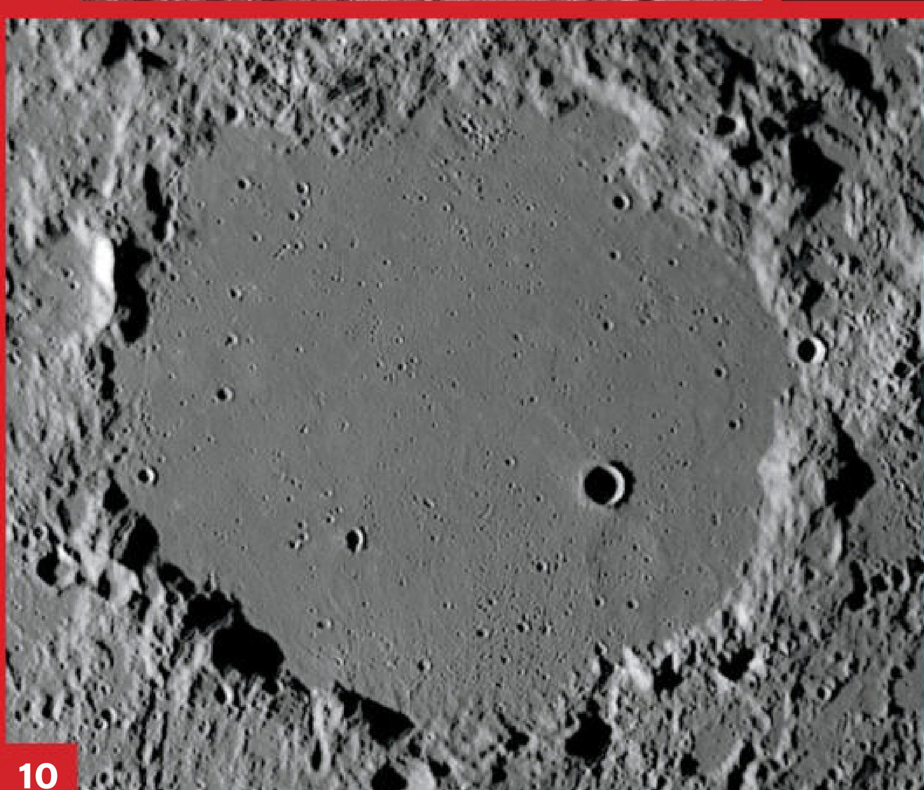
9 Lunar shadow play unlocks a linear fault known as the Straight Wall formation (Rupes Recta) in this image taken Feb. 23, 2018. The 68-mile-long (110 km) feature is surprisingly short, with a height of just 980 feet (300 m). To its right are craters (from top) Arzachel, Thebit, and Purbach.

10 Imaged under excellent seeing conditions Aug. 14, 2017, Ptolemaeus Crater shows incredible detail. The smallest crater pits resolved in this view are less than 0.6 miles (1 km) wide.

11 Great seeing conditions Oct. 28, 2021, enabled this stunningly detailed view of Clavius Crater.

12 Craters Theophilus (left) and Cyrillus (right) appear crisply defined in this April 2018 image processed for maximum detail.

13 Taken using a 14-inch Celestron, the HDR-processed image of Alphonsus (right) stacks up well with the LRO's shot shown at left. LEFT: NASA



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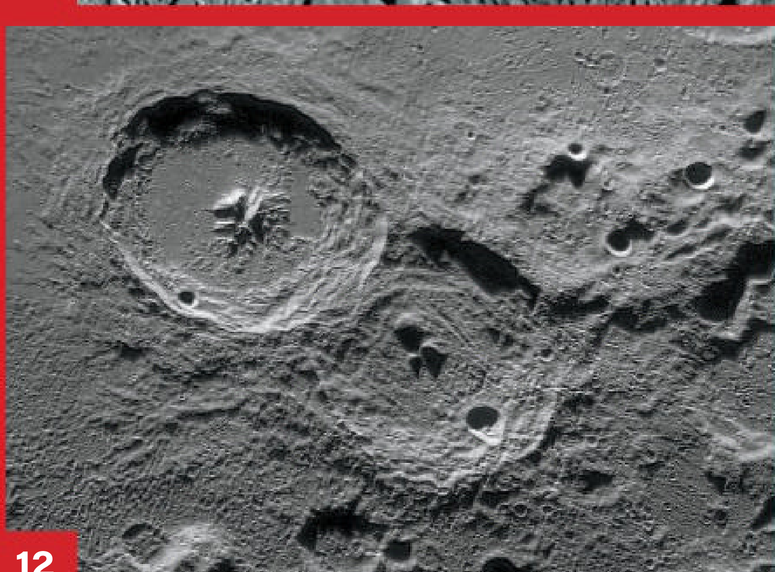

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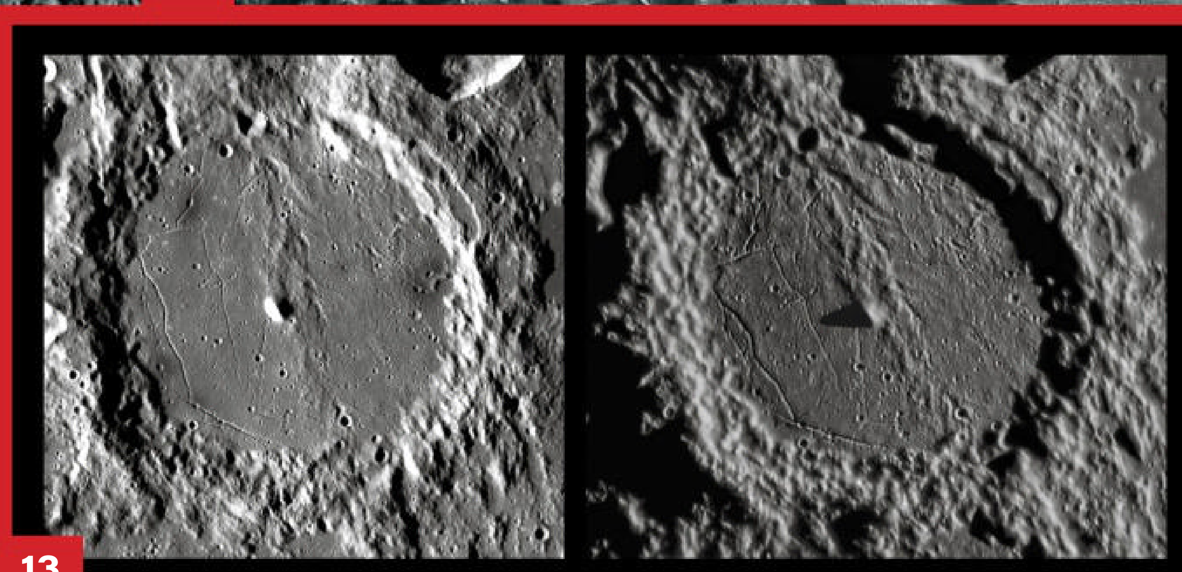

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lunar features. These can reveal unusual forms, as well as terrain features that are not readily apparent in other lighting conditions.

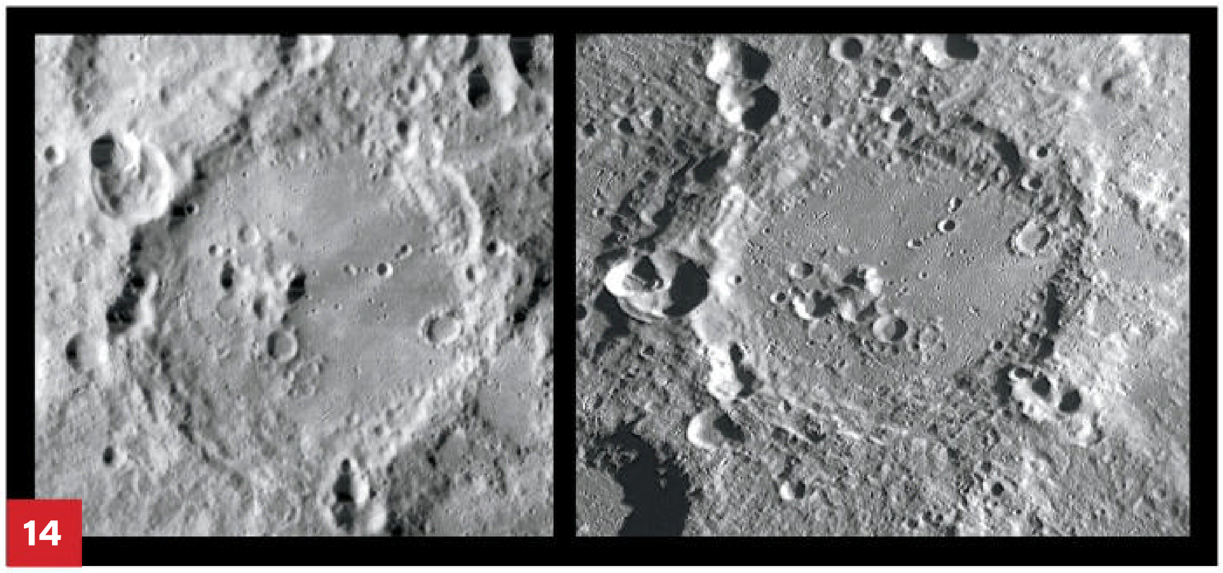
At approximately 108 million years old, the prominent and distinctive Tycho Crater is among the youngest impact features on the Moon. Its bright interior is particularly evident when the Sun is overhead, and its distinctive pattern of ejecta rays extends up to 930 miles (1,500 km) across the lunar surface.

The well-known trio of craters Ptolemaeus, Alphonsus, and Arzachel provides a good example of relative dating of lunar features. Of the three, only Arzachel has a well-defined, walled rim and prominent central peak. Alphonsus' wall and central peak are comparatively less well defined, and the interior of Ptolemaeus is almost fully lava filled and lacks any evidence of a central peak. Based on these morphologies, it is clear that Ptolemaeus is the oldest and Arzachel the youngest of the three. And digital photography is helping amateurs finally explore that lunar history for themselves.

Ramping up the resolution

In the past, astrophotography using film or photographic plates had major limitations. The silver halide crystals these methods used were inherently grainy and not very sensitive to light. To top it off, because exposures tended to require several seconds, they were also seriously affected by atmospheric turbulence or seeing. As a result, it was almost impossible to obtain diffraction-limited images — those with resolutions limited only by optics — with any telescope, large or small.

However, most of these limitations do not apply to digital photography. Because only the very best frames are combined and processed, a final digital image can approach the full resolution potential of the scope used to obtain it.



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"The future holds better images for me and everyone who puts their heart into pushing deeper into the heavens."
– Robert Reeves

Pushing the envelope

Most astrophotographers like to experiment with their avocation in an effort to squeeze every last bit of information out of their digital data, providing as detailed a view as possible. We are no exception.

One such method to get the most out of your data is to use processing techniques like high dynamic range (HDR). However, this will only work effectively with top-quality stacked images containing several hundred frames.

At this point, one might reasonably ask: Are there no limits to what amateur lunar imagers can hope to achieve in the future, or have we reached a pinnacle? Clearly, larger aperture telescopes will help you capture more impressive results by having a higher angular resolution. But will continuing improvements in digital cameras and data-processing applications expand those horizons even more? Only time will tell.

But then again, does it really matter? As expert imager Robert Reeves so nicely put it in his compelling 2016 Astronomy.com article, "Lunar landscapes love affair": "So why do I keep imaging the Moon after half a century? Simply said, I haven't done my best yet. I haven't finished exploring. There is more to see. The future holds better images for me and everyone who puts their heart into pushing deeper into the heavens, and I am going to enjoy the ride while I can!"

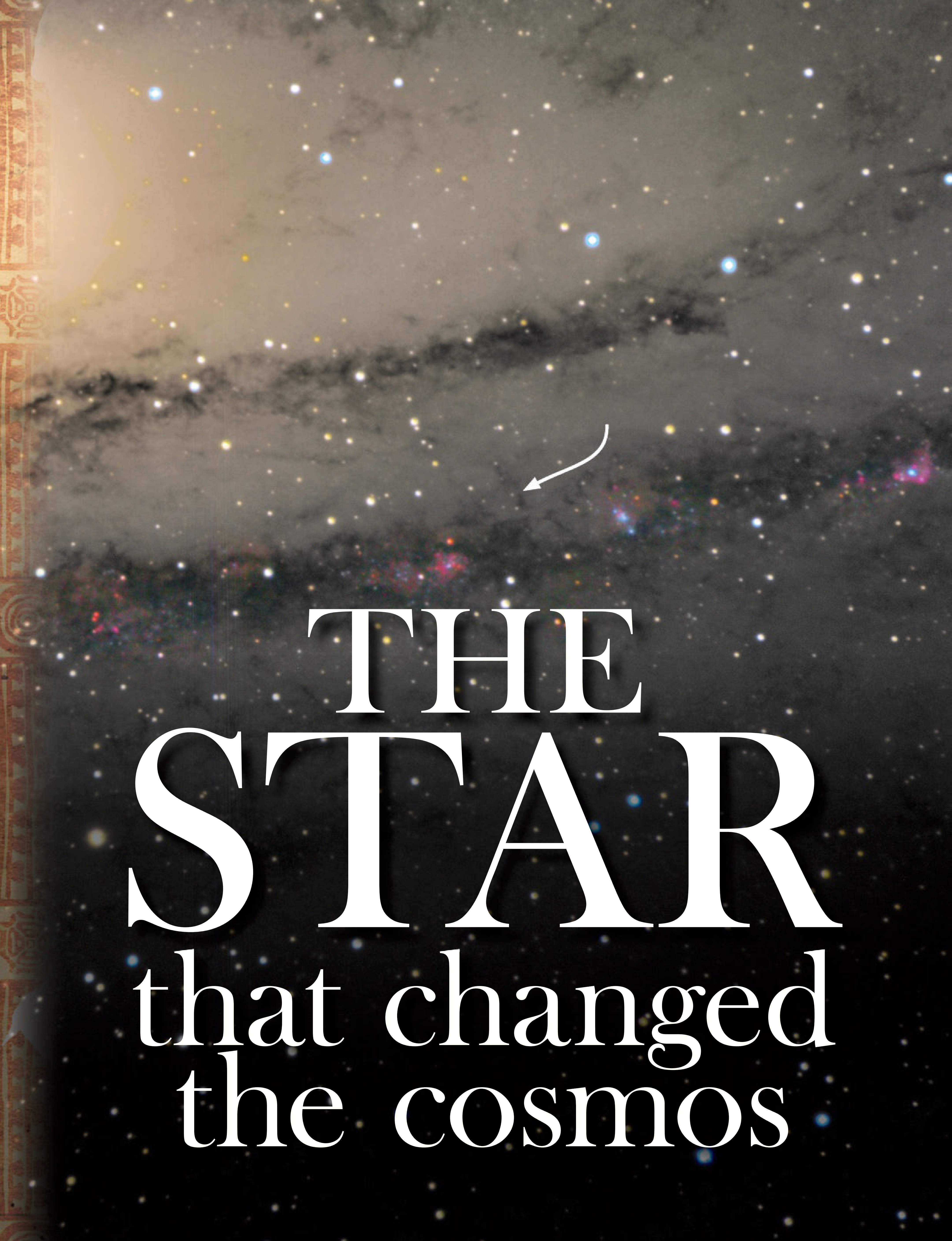
We could not agree more.

15

14 In 1967, Lunar Orbiter 4 captured this then-impressive view of Walther Crater, shown at left. But many more intricate details are revealed in the high-resolution, HDR-processed image at right, which was taken in 2016 using a 14-inch Celestron. LEFT: NASA

15 This spectacular image of craters Eudoxus (bottom) and Aristoteles (top), taken April 16, 2019, under exceptionally good atmospheric conditions, also reveals a wealth of detail in the surrounding regions. Such details are typically evident only under low-angle illumination.

Leo Aerts *and* **Klaus Brasch** *have both maintained a lifelong interest in astronomy, especially when it comes to observing.*



THE STAR that changed the cosmos

This colorful image shows a closeup of a portion of the Andromeda Galaxy's (M31) disk. The Cepheid variable star M31-V1 is indicated with an arrow. The shot is a composite of luminance data acquired on many of the 57 nights over which the author imaged, to which color data have subsequently been added.
ROD POMMIER

PARCHMENT SCROLL: FRENTA/DREAMSTIME

An astroimager follows in Edwin Hubble's footsteps to prove the utter vastness of our universe using a single star. **BY ROD POMMIER**

YOU KNOW THAT M31 (NGC 224) in Andromeda is another galaxy far outside our own Milky Way, don't you? Of course you do! Everyone knows that.

But we haven't *always* known it. In fact, we've only known for just under a century. Prior to that, astronomers referred to M31 and scores of other galaxies scattered throughout the sky as spiral nebulae. They were visible in great numbers in a bewildering variety of sizes, shapes, and orientations. But no one knew their distance. And their true nature was a hotly debated issue.

On April 26, 1920, astronomers Harlow Shapley of Mount Wilson Observatory and Heber Curtis of Lick Observatory held a Great Debate at the Smithsonian Institution in Washington, D.C. The topic: the nature of spiral nebulae and the scale of the universe. Shapley had measured the size of the Milky Way in 1915 and found it far larger than most astronomers had imagined. He argued the Milky Way was the entire universe and the spiral nebulae were smaller objects within it. Perhaps they were swirling stellar nurseries or condensing solar systems. Curtis argued they were galaxies, each like the Milky Way, and therefore extremely large and at vast distances. The debate had no clear winner.

Just a few years later, in 1923, Edwin Hubble settled it. Using the 100-inch Hooker Telescope and photographic glass plates at Mount Wilson Observatory, he discovered a variable star within M31. Hubble used that star to show M31 lies far outside the Milky Way, proving it had to be another galaxy. The universe suddenly got much bigger. In fact, if the myriad spiral nebulae that appeared smaller than M31 were also galaxies in their own right, they must be farther still. The universe had to be unbelievably enormous.

Edwin Hubble poses in front of a model of Mount Wilson's 100-inch Hooker Telescope in this photograph shot circa 1948, years after his groundbreaking 1929 paper calculating the distance to M31. While he was observing M31 and the variable star M31-V1, the Hooker reflector was the world's largest telescope.
HUB 1033 (11), EDWIN POWELL HUBBLE PAPERS, THE HUNTINGTON LIBRARY, SAN MARINO, CALIFORNIA

Hubble's star, the first variable found in M31, has since been dubbed M31-V1. It is the star that changed the cosmos.

Emulating Hubble

As an avid astrophotographer, I wanted to take my own image of this

star. But could I? I don't have a 100-inch telescope. I have a 14-inch telescope, which is magnitudes smaller. On the other hand, I do have a cooled CCD camera, which is much more sensitive to light than the photographic glass plates Hubble used. Could my smaller telescope with a more responsive detector possibly match a larger scope with less sensitive plates when looking at this faint target?

With some research, I found that 11 members of the American Association of Variable Star Observers (AAVSO) had successfully imaged M31-V1 in 2010 at the request of the Space Telescope Science Institute. Researchers wanted to know when the star was brightest to best image it with the Hubble Space Telescope (HST) for a public outreach program. The AAVSO report indicated they found M31-V1 a challenging but achievable target for modern CCD cameras and "larger" telescopes. How large was not reported. Still, their success convinced me I could at least attempt to image M31-V1 for myself.

Then a bigger question hit me. While imaging M31-V1, could I also use my images to prove M31 is another galaxy? That would be a fantastic project. After all, we are approaching the centennial of Hubble's discovery of M31-V1. What better time to emulate his work? To do that, I would not only need to duplicate Hubble's astrophotography; I would also need to understand how he used his images of M31-V1 to prove M31's distance.

A standard candle

Hubble determined the distance to M31 by finding a so-called standard candle within it. A standard candle is an object of known luminosity, or intrinsic brightness. If you know an object's luminosity, you can compare that to how bright it appears from your vantage point and work out how far away it must be. The standard candle Hubble found in M31, the star M31-V1, is a Cepheid variable star.

Cepheids are pulsating stars whose brightness varies over timescales ranging from one to more than 120 days. They exhibit a distinctive pattern on a graph of brightness versus time, called a light curve, consisting of a sharp increase in brightness followed by a gradual dimming. This pattern repeats at regular intervals, known as the period.

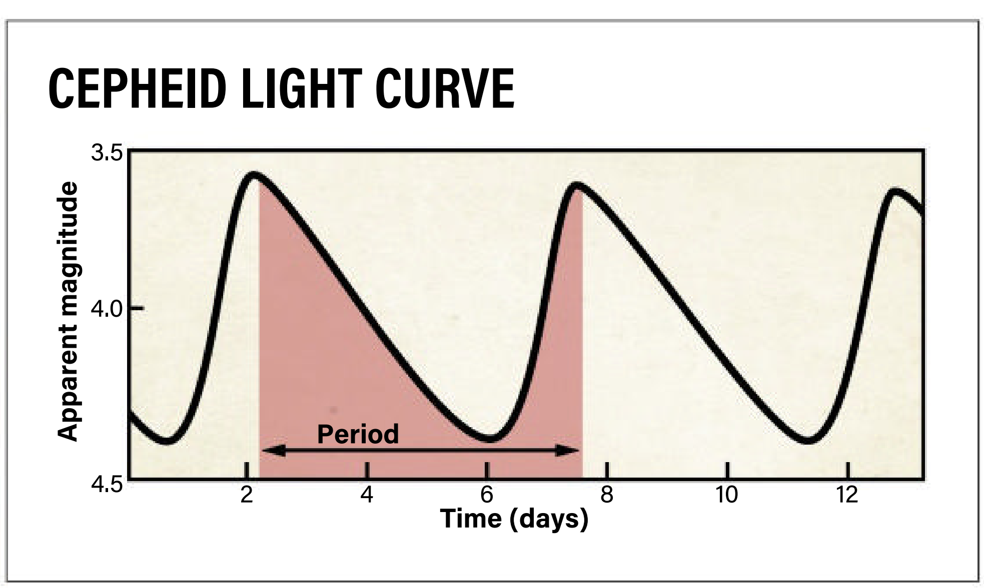
While working for the Harvard College Observatory, Henrietta Swan Leavitt discovered a relationship between a Cepheid's period and true luminosity. She noted that the longer a Cepheid variable's period, the brighter it appeared. In 1912, she published a graph showing a strong positive linear correlation between the logarithm of these stars' periods and average apparent magnitudes. This is now known as the period-luminosity relationship, or the Leavitt law.

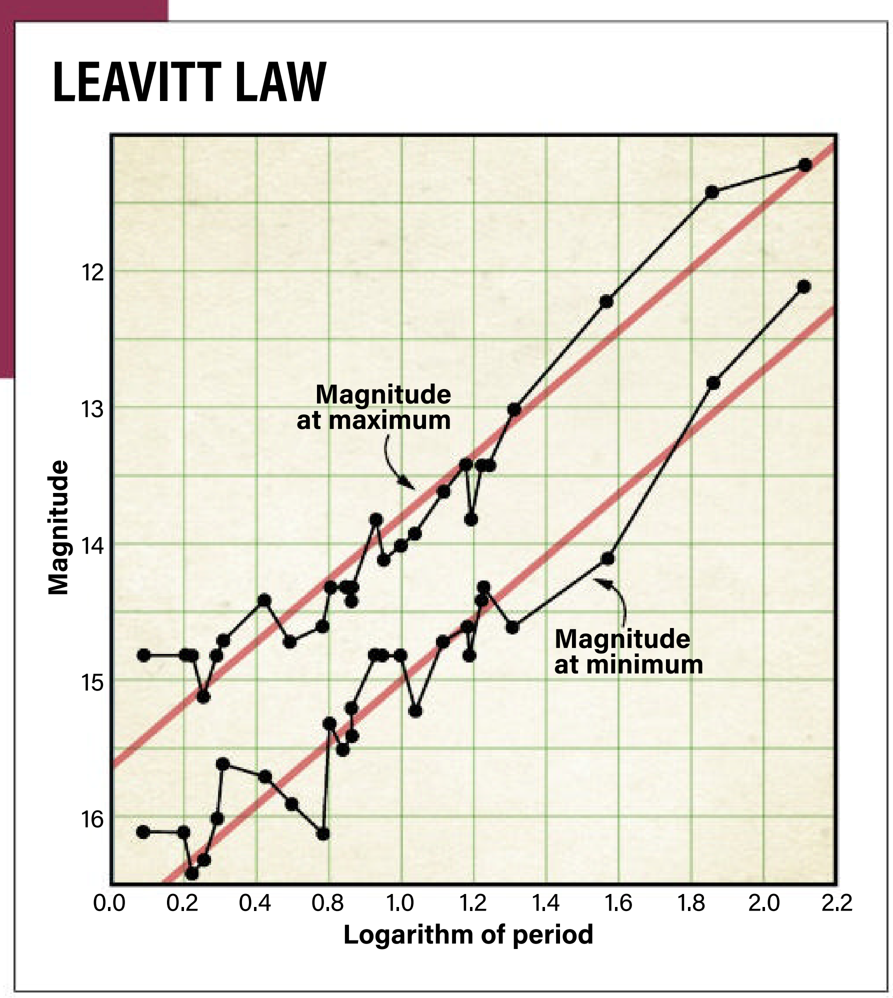
Danish astronomer Ejnar Hertzsprung realized the tremendous significance of Leavitt's discovery. Once calibrated, this relationship would allow astronomers to calculate the distance to any Cepheid from two pieces of data: its period and its average apparent magnitude. But Hertzsprung's early attempts at calibration were crude at best, yielding a distance to the Small Magellanic Cloud of 30,000 light-years, compared to the currently accepted value of 200,000.

Shapley revised the calibration but his work was also incorrect, leading him to estimate our galaxy's diameter was 300,000 light-years instead of the currently accepted 100,000. His measurements did correctly show we were at the outskirts of the Milky Way, rather than its center — the biggest demotion of our place in the universe since Copernicus put the Sun at the center of the solar system.

BELOW: Delta (δ) Cephei is the prototype Cepheid variable. This light curve shows its apparent magnitude versus time. All Cepheids produce a characteristic sawtooth pattern, with a rapid increase in brightness followed by a slow dimming. The timescale over which this pattern repeats is the period, and the difference between maximum and minimum brightness is the amplitude. Delta Cephei's period is 5.4 days and its amplitude is 0.7 magnitude. *ASTRONOMY*: ROEN KELLY, AFTER R NAVE/HYPERPHYSICS

RIGHT: Henrietta Swan Leavitt discovered a linear relationship between the logarithm of the periods of Cepheid variables, plotted on the x-axis, and their apparent magnitudes, plotted on the y-axis. This relationship was derived from 25 Cepheids in the Small Magellanic Cloud. The upper tracing and best-fit line show the stars' maximum magnitudes; the bottom tracing and best-fit line, their minimum magnitudes. Leavitt suggested the relationship could best be expressed using the stars' period and average apparent magnitude. This is now known as the period-luminosity relationship, or the Leavitt law. *ASTRONOMY*: ROEN KELLY, AFTER LEAVITT & PICKERING, 1912





However, a much bigger demotion was to come.

How Hubble did it

In September 1923, Hubble began taking serial exposures of M31 from Mount Wilson. On the night of Oct. 5/6, he made a 45-minute exposure on plate H335H. (The first H stands for Hooker, the last for Hubble.) Upon examination, he marked three stars in black with the letter N for *novae*, because they appeared to be new compared to earlier plates. However, he subsequently noticed that one of those three was present on earlier plates, including H331H taken the previous night. In fact, it appeared on archival plates as far back as 1909, but fluctuated in brightness. So, it couldn't be a nova and must be a variable star.

With a red pen, Hubble crossed out the letter N and wrote "VAR!" for *variable*. Why the exclamation point? Hubble realized that if this star was a Cepheid, he had struck astronomical gold. If he could determine the Cepheid's period and its average apparent magnitude, then he could calculate the distance to M31 and solve the mystery of the spiral nebulae.

In early 1924, Hubble imaged this star on as many successive nights as weather permitted and determined its nightly magnitude. His data produced the characteristic light curve of a Cepheid. He measured its period as 31.415 days and estimated its median apparent magnitude at 18.5. From the period, Hubble derived an absolute magnitude of –5.0. He then calculated that for a Cepheid this bright to exhibit an apparent magnitude of 18.5, it had to be nearly 1 million light-years away. Therefore, M31 could only be an enormous independent galaxy outside the Milky Way.

In 1929, Hubble published an estimated distance to M31 of 900,000 light-years, calculated using additional observations and Shapley's revised calibration of the period-luminosity relationship. The currently accepted distance to M31 is 2,537,000 light-years. The same errors that caused Shapley to overestimate the diameter of the Milky Way caused Hubble to underestimate the distance to M31.

Planning the project

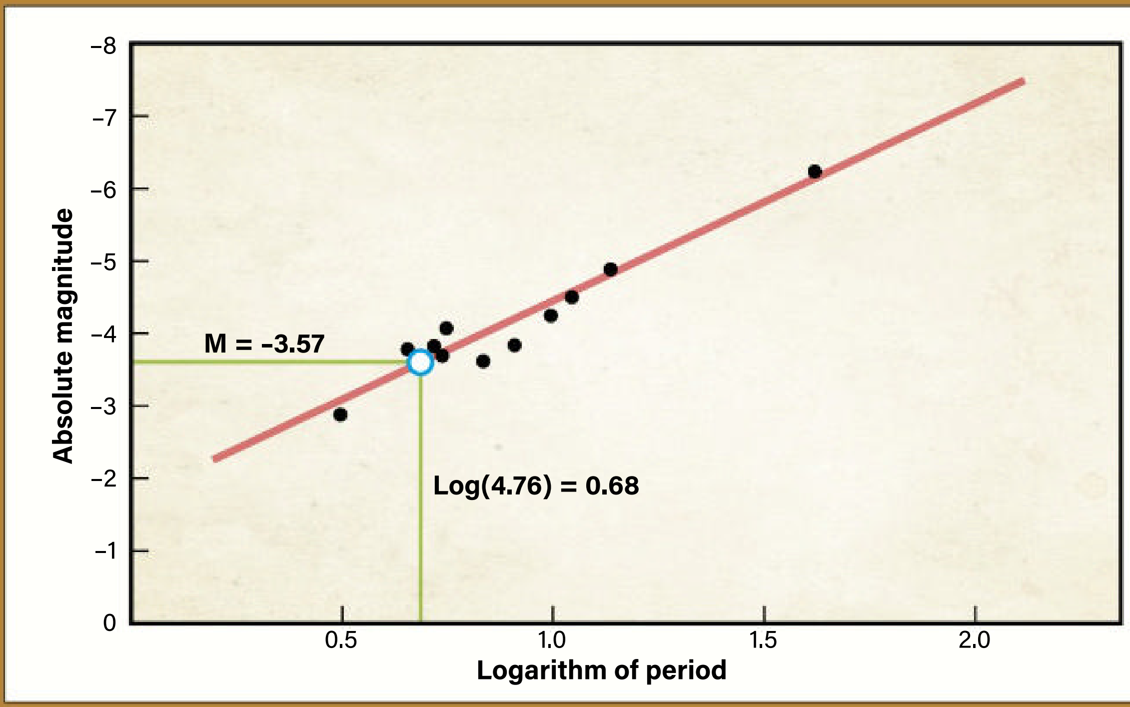
To reproduce Hubble's work, I needed to produce a light curve to determine both M31-V1's period and average apparent magnitude. Measuring magnitudes of stars on digital images is now done with photometry software, which determines the magnitude of a target star by comparing its brightness to that of a comparison star of known magnitude on the same image. My imaging software, MaxIm DL Pro, includes a tool to do this.

The AAVSO website's Star Plotter, which allows users to create star charts at various scales and orientations to match their images, includes comparison stars and their magnitudes. Fortunately for me, the AAVSO established many comparison stars within 15' of M31-V1 in preparation for their 2010 project

Research indicated that to obtain the most accurate magnitude measurements, I should bin my images to 1x1. Further, my telescope is a Schmidt-Cassegrain, which is subject to mirror flop — a shift in mirror position with actions such as focusing or parking the telescope. Mirror flop can significantly change the illumination of a CCD chip between imaging sessions, affecting magnitude readings. Therefore, I committed to shooting new flat field calibration frames each night.

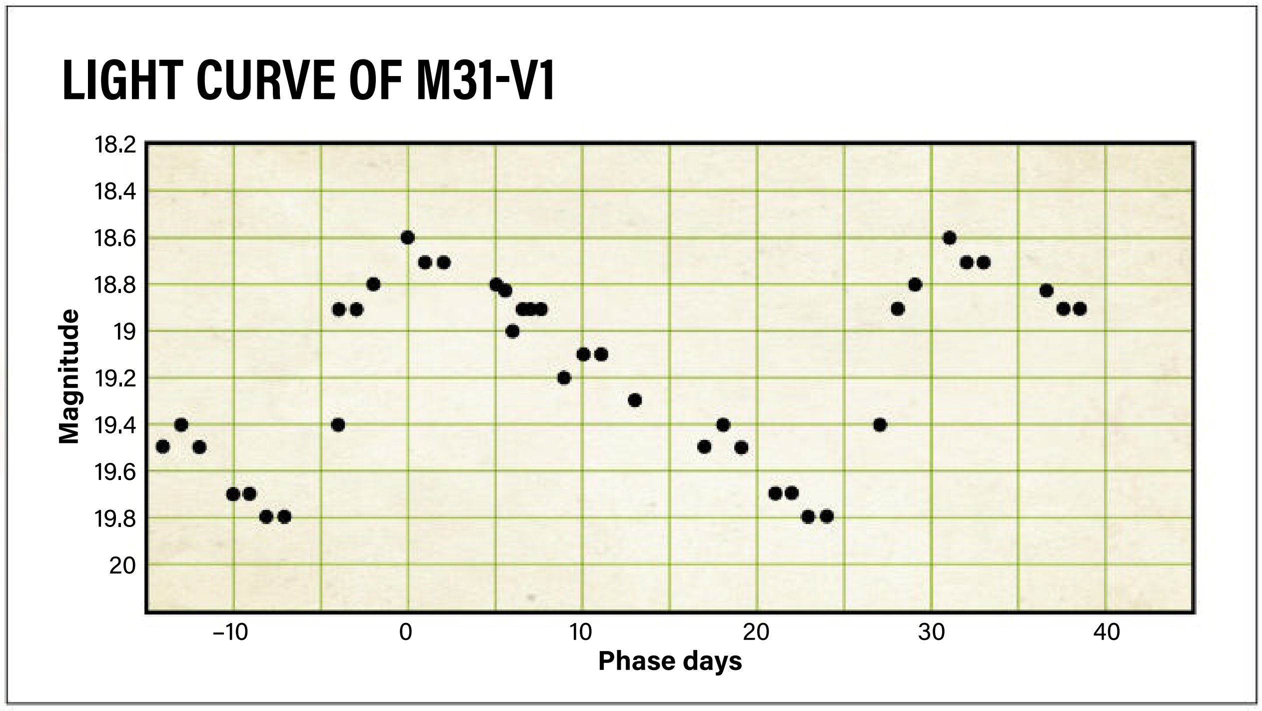
I imaged through a clear filter to capture as many photons as possible and used an f/7.5 focal reducer/corrector to reduce exposure time. M31 spans the width of six Full Moons across the sky, so only a portion of it would fit within my scope's field of view. Therefore, my first tasks were to determine M31-V1's location within M31 and how best to frame it on my CCD chip.

CALIBRATED PERIOD-LUMINOSITY RELATIONSHIP

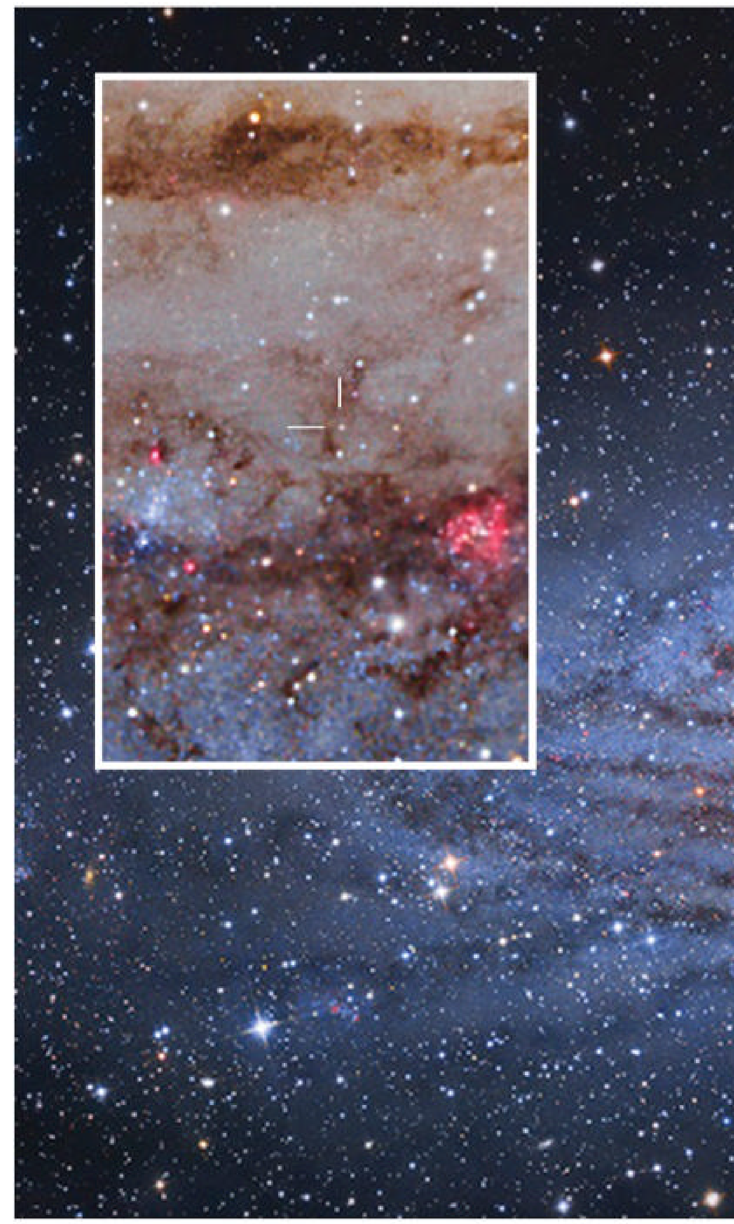


This graph shows the period-luminosity relationship, calibrated by measuring the distances to Cepheid variables in the Milky Way. These distances can be used to calculate the stars' true luminosities, or absolute magnitudes, to calibrate the y-axis of the graph. Calibration enables use of any Cepheid variable as a standard candle, whose distance can be determined from only its period and average apparent magnitude. In this case, an example Cepheid with a period of 4.76 days yields an absolute magnitude of –3.57. *ASTRONOMY*: ROEN KELLY, AFTER AUSTRALIA TELESCOPE NATIONAL FACILITY

Hubble's glass photographic plate H335H, obtained with the 100-inch Hooker Telescope Oct. 5/6, 1923, shows the galaxy M31. Three "new" stars are marked in black with the letter N. However, Hubble later noted that the star at the top right was present on earlier plates but fluctuated in brightness. He subsequently crossed out the N and marked it with "VAR!" in red. This is the Cepheid variable M31-V1, which Hubble used to calculate the distance to M31 and solve the mystery of the spiral nebulae. COURTESY OF CARNEGIE INSTITUTION FOR SCIENCE



Incorporating data from observations made over 57 nights, the author's light curve exhibits the characteristic pattern of a Cepheid variable. From this light curve, the author obtained the star's period of 31.91 days, peak apparent magnitude of 18.6, minimum apparent magnitude of 19.8, average apparent magnitude of 19.2, and amplitude of 1.2 magnitudes. *ASTRONOMY*: ROEN KELLY, AFTER ROD POMMIER



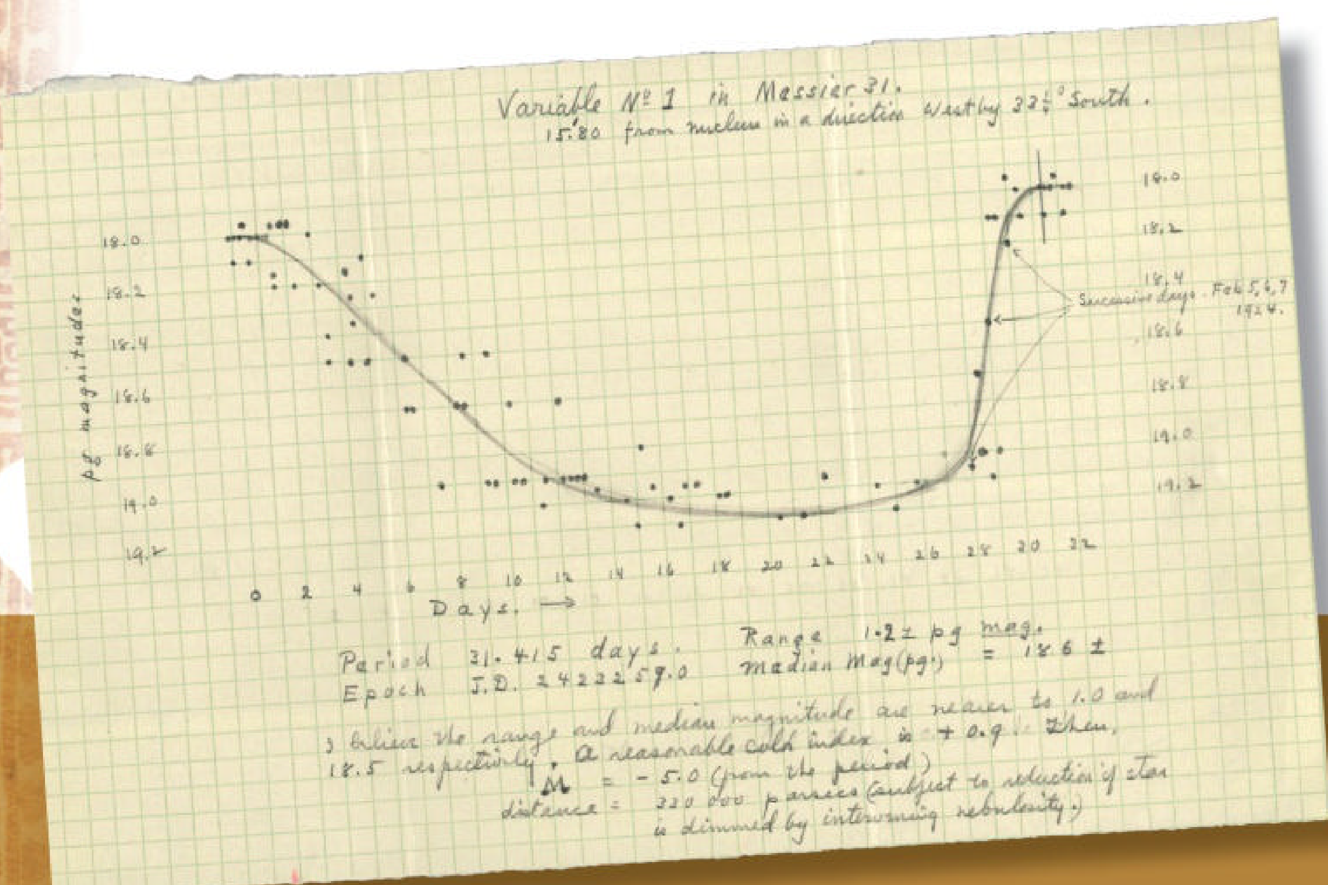
M31-V1 is at R.A. 00h41m27.3s, Dec. 41°10'10.4", in the northeast quadrant of M31. Using imaging-planning software, I determined turning my CCD camera to a rotation angle of 135° and aiming at R.A. 00h41.1m, Dec. 41°11' placed M31-V1 near the center of my chip. This orientation would also include the magnitude 9.27 foreground Milky Way star SAO 36590 as a suitable guide star in my off-axis guider, allowing for accurate tracking during imaging sessions. Several AAVSO comparison stars were present on my images.

Hubble didn't know how many nights he would have to image M3-V1 to determine its period, but with the benefit of his work, I knew it would require at least a month and likely longer. A Cepheid's period is most reliably measured between dates of maximum brightness. I didn't know where M31-V1 would be in its cycle during my first observation. Therefore, I'd likely have to continue imaging until it peaked in brightness and carried out another full cycle until it peaked again. That meant I'd have to image some nights with a nearly Full Moon, which unfortunately would be in the vicinity of M31 during upcoming months. Bright moonlight flooding down my telescope tube might completely wash out M31-V1, especially if the Full phase coincided with the dim portion of the star's cycle.

Then, there was weather. Hubble worked in sunny southern California, where he had only a few cloudy nights. I live in rainy Portland, Oregon, where even clear nights are often interrupted by clouds rolling in. There was also a risk of heavy smoke obscuring the sky for long periods during the upcoming wildfire season. This would indeed be a challenge.

Imaging the star

I began imaging in early August, a time when M31 rises above 45° altitude by 1 A.M. I calibrated and stacked the first night's sub-exposures into a single integrated image. Then I zoomed in on the region containing Hubble's Cepheid for



Hubble created this hand-drawn light curve for M31-V1 from images obtained in early 1924. From these data, he showed that the star had the characteristic light curve of a Cepheid with a period of 31.415 days and an average apparent magnitude of 18.5. Using those data, he calculated that M31 had to be nearly 1 million light-years from Earth — therefore, so far away it must be a separate galaxy. COURTESY OF THE HARVARD UNIVERSITY ARCHIVES

INSET: A color image shows a closeup of M31-V1, marked with ticks, against the dusty background of M31's spiral arms. It is a small portion of this larger mosaic of M31, made by shooting 11 frames vertically along the axis of the galaxy with a 14.5-inch f/8 Cassegrain, filling in the rest with a 6-inch refractor. Each sub-exposure was 20 minutes in length. TONY HALLAS

inspection. M31-V1 appeared as a small, faint dot right where it was supposed to be! I stopped and stared at that star for a long time. During my 35 years as an astrophotographer, I have captured and inspected countless stars in my shots. This star was as inconspicuous and seemingly insignificant as any I had ever seen. Yet no other star I have imaged has been more important to cosmology and our understanding of our place in the universe than this small, dim one. Seeing the star that changed the universe on an image I had made myself took my breath away.

Spurred on by my initial success, I eagerly returned to my backyard observatory every clear night. I couldn't wait to see if and when M31-V1 changed in brightness. As the Moon waxed toward Full, the star grew dim and I was concerned it might soon disappear from my images. My fears were allayed as it suddenly brightened, quickly reaching a peak. I continued imaging for weeks afterward, as it slowly faded again. As the Moon once again approached Full, the star quickly brightened, reaching a second peak. I observed every clear night for another couple of weeks as it faded for a third time. At that point, having imaged over a period of 57 nights, I knew I had collected data for more than one full period.

With my imaging completed, I calibrated and stacked all the sub-exposures from each night into an integrated image for that date. I was ready to make my own light curve of M31-V1.

Making light curves

I calibrated my photometry software on a comparison star near the center of each image. This worked extremely well — my magnitude readings on all other comparison stars read accurately to within a few hundredths of a magnitude. That gave me confidence my recorded magnitudes for M31-V1 were also accurate. Although my software displays magnitude readings to three decimal places, I could only justify reading M31-V1's brightness to the nearest 0.1 magnitude because the magnitudes of comparison stars in my chart were given only to one decimal place.

After measuring M31-V1's magnitude on all my images, I plotted these by date on a graph. The resulting light curve definitely exhibited the characteristic pattern of a Cepheid. I could now derive the period and apparent magnitude to calculate the distance to M31.

The apparent magnitudes for the first and second maxima were 18.6 and both minima were 19.8. Therefore, the amplitude of my light curve was 1.2 magnitudes and the average apparent magnitude was 19.2. The difference in Julian dates for the maxima yielded a period of 31.91 days. Although this is not the period of 31.415 days derived by Hubble, the small difference had no appreciable impact on my calculated absolute magnitude. This is because the period-luminosity relationship uses the logarithm of the period to obtain absolute magnitude. The logarithms of 31.91 and 31.415 both round to 1.5.

The distance to M31

To compare my results for the distance to M31 directly to Hubble's, I needed to use Shapley's flawed calibration of the period-luminosity relationship. Curiously, Hubble adjusted this graph to yield absolute magnitude at maximum, rather than the average absolute magnitude as

ABOVE: This calibrated and stacked image — greatly zoomed in — from the author's first night of observation shows M31-V1, indicated by an arrow, as a faint dot, right where expected. ROD POMMIER

ABOVE RIGHT: The author measured the nightly apparent magnitude of M31-V1 using the photometry tool in MaxIm DL Pro. After calibrating the tool on a non-variable star of known magnitude, he could confidently read the magnitude of M31-V1. This image, in which the tool's bull's-eye is centered on M31-V1, shows the star's magnitude as 18.7 (to the nearest 0.1 magnitude). ROD POMMIER

originally suggested by Leavitt and used in virtually all other calibrations. Hubble indicated he believed his maximum magnitude readings were more reliable than those obtained during dimmer portions of the cycle. Based on this graph, the logarithm of my 31.91-day period yielded an absolute magnitude for M31-V1's maximum of –3.6.

Once you have an object's absolute magnitude and corresponding apparent magnitude, it is simple to calculate its distance using an equation called the distance modulus: $m - M = 5[\log_{10}(d/10)]$, where m is the apparent magnitude, M is the absolute magnitude, and d is the distance in parsecs. (One parsec is equal to 3.26 light-years.) Solving this equation for d gives $d = 10^{(m-M+5)/5}$.

My values for m and M yielded a distance of 275,423 parsecs, or 897,879 light-years — very close to Hubble's published value of 900,000. With this, I had accomplished my goal. Despite the flawed calibration, I had also proven M31 is so far away it must be a separate galaxy.

I was extremely pleased that my result was so close to Hubble's. The difference was only 2,121 light-years. Then, while reading Hubble's 1929 publication again, I noticed something remarkable. Although Hubble did not show his values for maximum apparent and absolute magnitude, he gave their difference: $m - M = 22.2$. That was precisely the value I had obtained! That could only mean Hubble had obtained exactly the same distance: 897,879 light-years. He simply rounded to 900,000 light-years in his paper. Now I was thrilled. I had done in my backyard what Hubble did at Mount Wilson, with precisely the same result.

Still, that result is incorrect because it is based on an incorrect calibration of the period-luminosity relationship. Since 1929, as technology has improved, the calibration has been revised. This has greatly increased the calculated distance to M31. With the advent of HST, that number is now 2.537 million light-years.

A memorable endeavor

With that, I declared the project a great success. Following in Hubble's footsteps was an exhilarating experience I will certainly remember for the rest of my life. Most of all, I am amazed that I, a mere amateur astronomer using equipment in my backyard, was able to reproduce a feat that less than a century ago was accomplished by the world's greatest astronomer using the world's largest telescope.

This is a testament to amateur astronomy as a hobby. Want to be an amateur archaeologist or paleontologist? Good luck accessing an Egyptian tomb or a *T. rex* fossil bed to conduct your own research projects. Such valuable materials are reserved exclusively for professionals.

Not so with amateur astronomy. All astronomers have unrestricted access to the same crucial resource: the entire sky above us. And with that, the sky is truly the limit of what we amateurs can do.

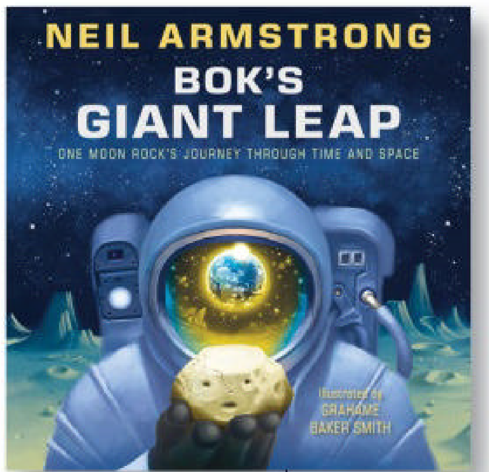
UP TO DATE

One of HST's chief goals was to precisely determine distances to 10 Milky Way Cepheids by measuring their trigonometric stellar parallaxes — which can only be done from space — to produce a calibration of unprecedented accuracy for the period-luminosity relationship.

The equation for the period-luminosity relationship using the HST calibration is: $M = (-2.43 + 0.12)[\log_{10}(P)-1.0] - (4.05 + 0.02)$, where M is absolute magnitude and P is the period.

Using my data with the HST calibration, how close could I come to the currently accepted distance of M31? My period of 31.91 days yields an absolute magnitude of –5.27 using this calibration. Then the distance modulus gives a distance of 776,247 parsecs or 2.531 million light-years. *— R.P.*

Rod Pommier *is a surgeon and longtime deep-sky observer who has written many articles for* Astronomy.



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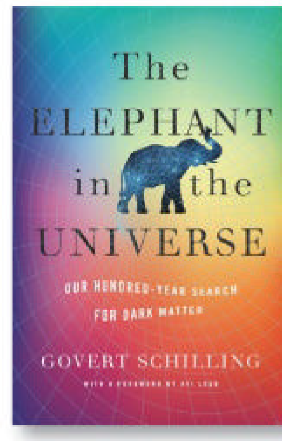

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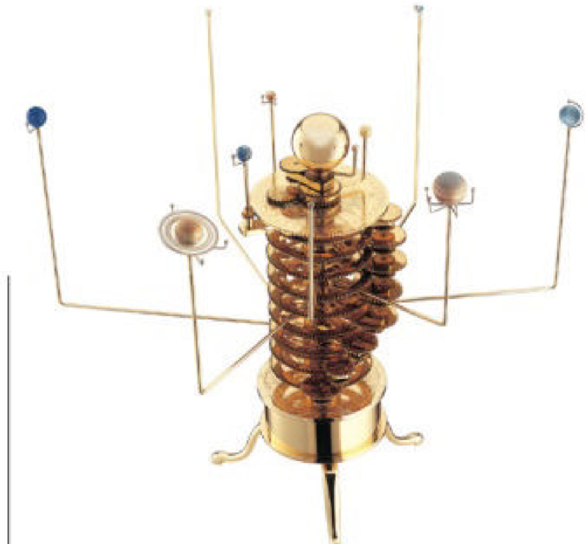

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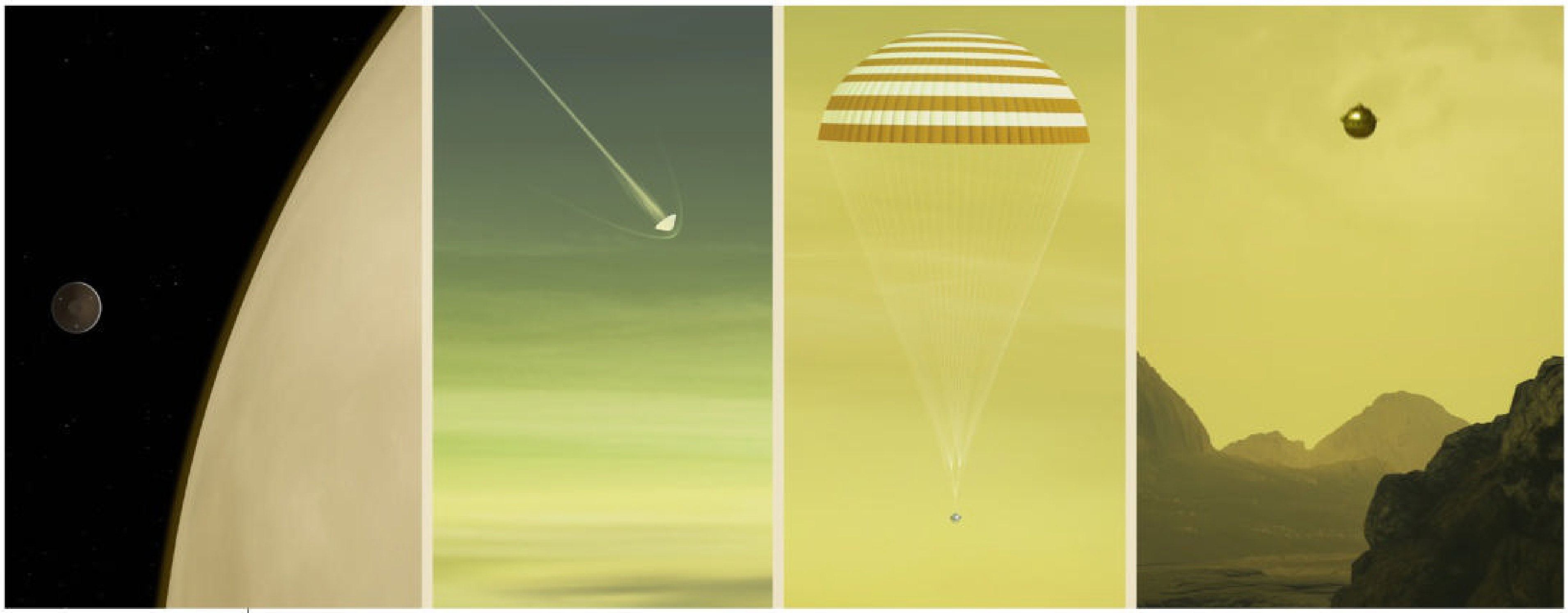


DAVINCI has an intricately planned descent stage to make the most of its hour-long trip through Venus' atmosphere. NASA GSFC VISUALIZATION AND CI LABS MICHAEL LENTZ AND COLLEAGUES

Skydiving onto Venus

Q WHY WILL DAVINCI JETTISON ITS PARACHUTE SO QUICKLY INTO VENUS' ATMOSPHERE? WON'T THIS RESULT IN LESS TIME TO COLLECT DATA AND IMAGES?

Steven Portalupi
Newmarket, New Hampshire

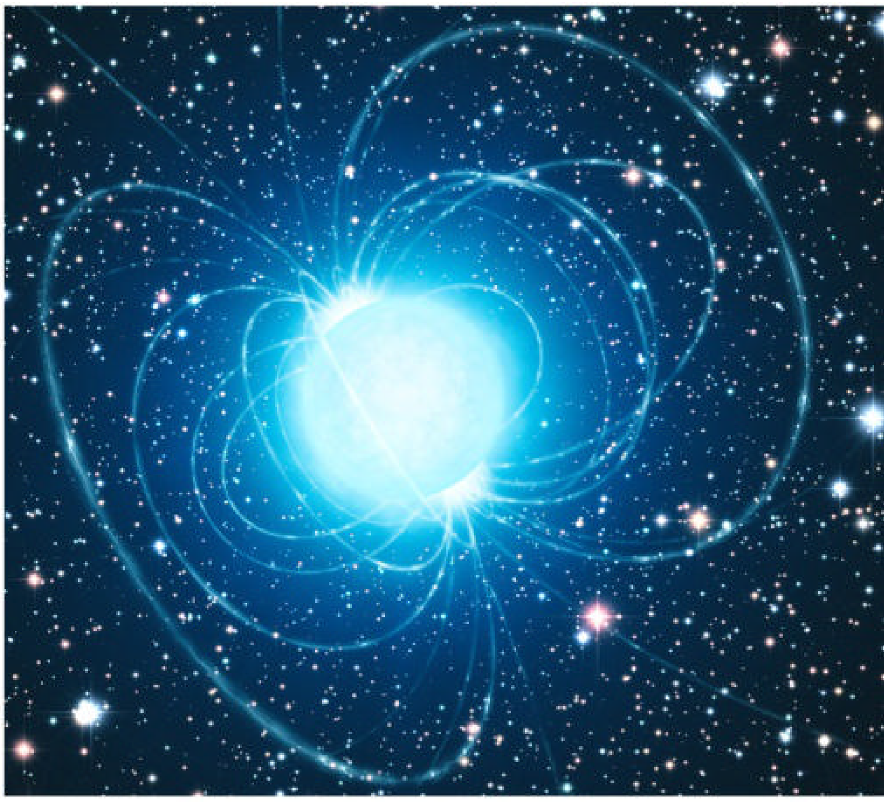
A Venus and its massive atmosphere present an incredibly challenging environment for any in situ probe mission. The planet's surface temperature is approximately 860 degrees Fahrenheit (460 degrees Celsius) thanks to the dense CO_2 atmosphere, which also creates a surface pressure 90 times greater than Earth at sea level.

Sulfuric acid clouds exist roughly 25 to 43 miles (40 to 70 kilometers) above the surface in a thick layer. When the DAVINCI descent sphere spacecraft (DS) jettisons its main parachute approximately 32 minutes into the descent — around 24 miles (39 km) above the surface — the temperature will already be 304 F (153 C).

This truly hellish environment presents challenges that other planetary probes don't have to face. Trying to build a parachute that could survive these conditions would be risky and expensive. Thus, DAVINCI employs fixed drag plates to slow its descent after jettisoning the parachute. The thick venusian atmosphere also helps because the descent is more like settling into a fluid than falling through air.

It's true that by cutting the parachute loose, the DS will spend less time in Venus' lower atmosphere. But in many ways, this is an advantage because the craft spends less time exposed to the harsh conditions there. If the DS remained longer on the parachute, it would need to be designed to absorb more heat to keep the internal science instruments cool and have larger batteries to keep the craft operating longer through the descent. This would increase the weight, which makes it even more challenging to build a parachute to support it!

To ensure DAVINCI meets its science objectives, the DS makes use of state-of-the-art chemistry instruments



With a magnetic field over a thousand trillion times greater than Earth's, magnetars are the reigning magnetic kings of the cosmos. ESO/L. CALÇADA

and telecommunications systems that can sample the atmosphere every 500 feet (150 meters) of descent and take near-infrared images every few seconds. The DS will transmit this data to its companion craft in venusian orbit, the Carrier Relay Imaging Spacecraft (CRIS), before reaching the surface. So, in the short hour that DAVINCI will spend in Venus' atmosphere, it will acquire groundbreaking measurements and images far beyond what any previous mission has managed.

Colby Goodloe
DAVINCI Descent Sphere Lead Engineer, NASA Goddard Space Flight Center, Greenbelt, Maryland, on behalf of the DAVINCI Project

Q I'VE READ THAT THE STRENGTH OF A NEUTRON STAR'S MAGNETIC FIELD IS GREATER THAN ANY OTHER FOUND IN THE UNIVERSE. WOULDN'T A SUPERMASSIVE BLACK HOLE HAVE A STRONGER ONE?

Patrick Clough
Wichita, Kansas

A The answer to this question is quite complicated. There is a so-called no-hair theorem, which basically states that only three observable parameters can be determined for each black hole: its mass, electric charge, and rotation. The hair here is a metaphor for all other possible parameters, including magnetic fields, which disappear inside the black hole and become inaccessible to scientists. So, a black hole by itself does not have any measurable magnetic field.

However, any matter that accretes onto a black hole could be magnetized. In this case, the magnetic field will become stronger as the matter approaches the black hole and is compressed. So, magnetic fields do exist around supermassive black holes, but their source is the accretion disk, not the black hole itself.

For example, when the Event Horizon Telescope collaboration imaged the supermassive black hole in M87, they observed radio waves that were polarized by the magnetic field in the surrounding accretion disk. The team estimated the magnetic field strength to be between two to 50 times stronger than Earth's magnetic field. But that is a tiny magnetic field compared with the magnetic fields around pulsars and magnetars. In particular, magnetars retain the strongest magnetic fields in the universe, at a thousand trillion times stronger than Earth's field.

Andrei Igoshev
Astronomy Research Fellow, University of Leeds, Leeds, United Kingdom

Apollo 11 astronauts captured this image of Earth rising above the Moon's horizon in July 1969. NASA

Q AT WHAT RATE IS THE MOON MOVING AWAY FROM EARTH? WHAT KINDS OF CONSEQUENCES WILL OUR PLANET SEE AS OUR SATELLITE MOVES FARTHER AWAY?

Eliot H. Ginsberg
Riverview, Florida

A Let's first look at *why* the Moon is moving away from us. It boils down to one of Newton's laws: conservation of angular momentum. As the Moon's gravity pulls on Earth, it produces tidal forces that make the oceans bulge and cause Earth's rotation to lose momentum. Slowing Earth's rotation in turn speeds up the Moon's orbit, which must expand to conserve the total momentum of the Earth-Moon system.

The Moon is moving away from Earth at about 1.49 inches (3.78 centimeters) per year. And as it moves away, its orbital period increases and Earth's rotation slows down. Looking at the average rate of retreat over the last 4 billion years, it should take about 50 billion years before the Moon takes as long to complete one orbit as Earth takes to complete one rotation.

At this point, Earth will be tidally locked to the Moon, which will always sit above the same point on the planet. Only half of the planet will ever see the Moon. The Moon's changing impact on our tides would also cease, though there would still be some time-dependent tides, thanks to the Sun. The Sun-Earth tidal tug-of-war would eventually reverse the Earth-Moon process, bringing the Moon steadily closer to Earth until our planet's gravity tore it apart.

Of course, in 50 billion years, the Sun will have long since become a white dwarf. (This will happen in 10 billion years.) And, in all likelihood, Earth and the Moon will not survive the Sun settling into its twilight years.

Caitlyn Buongiorno
Associate Editor

SEND US YOUR QUESTIONS

Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Cosmic portraits


1


2


3

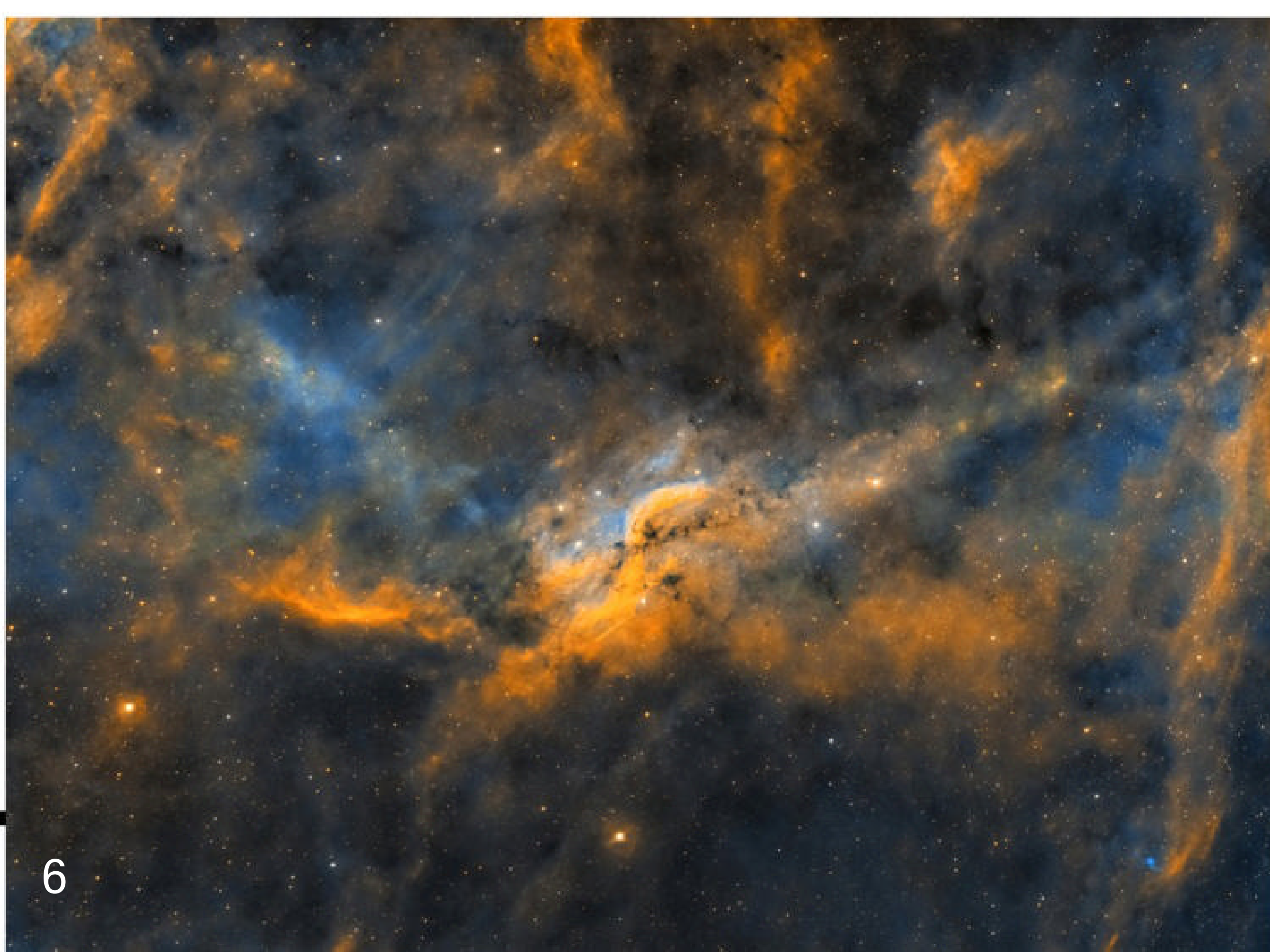
1. COLORFUL CLOUD
The emission nebula Sharpless 2–124 lies about 15,000 light-years away in Cygnus the Swan. This image consists of 15 hours of exposure time with a 4.2-inch scope in the Hubble palette. ▪ ***Emil Andronic***

2. OFF THE BEATEN PATH
The object Kohoutek 2–1 (PK 173–05.1) in Auriga has been cataloged as an irregular galaxy, an HII region, and a reflection nebula. But its relative brightness through an OIII filter suggests that it is, as Czech astronomer Luboš Kohoutek originally categorized it in 1963, a planetary nebula. This image was taken over nearly 47 hours in OIII with a 4-inch scope.
▪ ***Douglas J. Struble***

3. THROWN FOR A LOOP
The Helix Galaxy (NGC 2685) is an unusual polar ring galaxy, with tendrils of stars and dust coiled around the disk's main plane. Roughly 40 million light-years distant in Ursa Major, it glows at magnitude 12.7. The imager used 6-inch scopes and 20.4 hours of exposure time in LRGB filters.
▪ ***Peter Goodhew***

4

5



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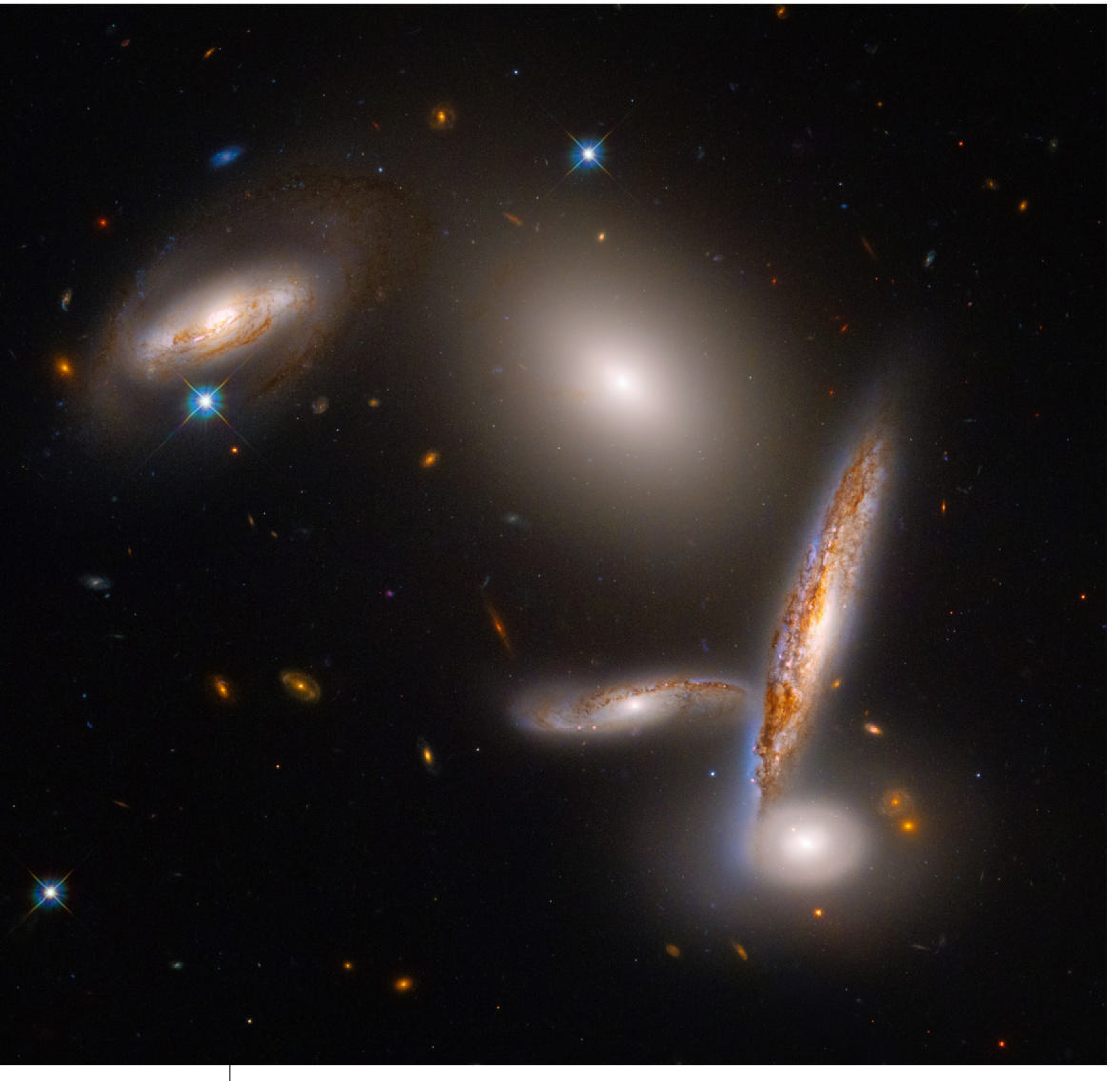
4. MILK AND ROSES
The Milky Way arches over Rose Lake, Idaho, in this panorama of sixteen 13-second exposures. The lit areas are not intentionally light-painted, but the result of light pollution from residences. **• *Ron Reeve***

5. RIGHT ON TARGET
A green flash occurs when, near sunset or sunrise, the atmosphere bends red, orange, and yellow light away from an observer. In this meticulously planned composite image, the photographer captured a green flash through the arches of Meloria Tower, an 18th-century landmark built on a tiny islet near Livorno, Italy. **• *Marco Meniero***

6. CHURNING UP THE COSMOS
The Propeller Nebula (DWB 111) in Cygnus would seem to have been produced by a rotating object flinging material into space. But, curiously, the object has no central star. A 2021 study found the region is likely excited by the star WR 140, about 50′ away. This image taken with Hubble palette filters represents eight hours of exposure through an 8-inch scope. **• *Chuck Ayoub***

SEND YOUR IMAGES TO:
Astronomy Reader Gallery, P.O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@astronomy.com.**



TOO CLOSE FOR COMFORT

Although the recently deployed James Webb Space Telescope may represent the future of space-based astronomy, the venerable Hubble Space Telescope still rules the present. If you have doubts, explore this dramatic image of Hickson Compact Group 40. This eclectic collection holds three dust-laden spiral galaxies, one elliptical galaxy, and one lenticular (lens-shaped) galaxy. The five island universes crowd into a region less than twice the diameter of the Milky Way's disk. Gravity is slowly pulling the galaxies together, and astronomers estimate that they will collide and merge into a single giant elliptical in a billion years or so. Hickson Compact Group 40 lies some 350 million light-years from Earth in the constellation Hydra the Water Snake. NASA/ESA/STSCI

October 2022

Giant planets rule the night

As twilight fades to darkness this month, **Saturn** stands out from its perch high in the northern sky. The ringed planet shines at magnitude 0.5 against the relatively faint backdrop of Capricornus the Sea Goat. The 4th-magnitude star Iota (ι) Capricorni lies less than 1° southwest of the solar system's second-largest world.

Saturn's high altitude makes it the top choice for early evening telescope viewing. Even the smallest scope shows the planet's 18"-diameter disk surrounded by a spectacular ring system that spans 40" and tilts 15° to our line of sight. During moments of good seeing, the Cassini Division appears as a dark gap between the outer A ring and the brighter B ring. Small instruments also reveal 8th-magnitude Titan, Saturn's largest moon, along with a trio of 10th-magnitude moons.

Jupiter hangs low in the east during twilight in early October. Look for the giant planet's position to improve dramatically, however, as both the evening and the month wear on. Jupiter gleams at magnitude –2.9 among the background stars of southern Pisces the Fish. That is some 400 times brighter than the constellation's luminary, magnitude 3.6 Eta (η) Piscium.

Once Jupiter climbs high in the north later in the evening, spend some time viewing it through your telescope. The solar system's largest world lives up to its reputation in October. The planet spans 50" to start the month and 48" as the calendar turns to November. Small scopes reveal a wealth of detail in Jupiter's massive atmosphere. Look for a series of alternating dark belts and brighter zones that run parallel to one another. The Great Red Spot should be obvious if it is on the hemisphere facing Earth. And be sure to check out the planet's four bright Galilean satellites.

The next bright planet doesn't put on a good show until after midnight. Once the familiar shape of Orion the Hunter fully clears the eastern horizon, you'll easily spot **Mars** to the constellation's lower left. The Red Planet resides in eastern Taurus the Bull, sharing this part of the sky with two other ruddy objects: the 1st-magnitude stars Aldebaran in Taurus and Betelgeuse in Orion. Mars dominates its neighbors, however, brightening to magnitude –1.2 by October's close.

Mars suffers from a low altitude this month as it travels along the northernmost part of the ecliptic. It reaches a peak altitude of just 30° to 40° as morning twilight commences. Still, the view through a telescope proves worthwhile because the planet's diameter grows from 12" to 15" during October. This is big enough that most scopes will show surface details under good seeing conditions.

Mercury lies in the morning sky this month, reaching greatest western elongation October 8. Unfortunately, the planet then stands only 18° from the Sun. This small separation combines with the shallow angle between the eastern horizon and the ecliptic to make spotting the inner world nearly impossible from mid-southern latitudes.

Venus passes on the far side of the Sun from our vantage point October 22 and remains out of sight all month.

The starry sky

As the winter Milky Way dips low in the west on October evenings, turn your attention away from our galaxy's plane. One of my favorite sights at this time of year is the constellation Grus the Crane, which lies nearly overhead in the evening sky.

I first became familiar with this bird in March 1970 when I was keenly following the progress of Comet Bennett as it headed northwest through the constellation. At one point, the comet passed close to the striking naked-eye pair Delta^1 (δ^1) and Delta^2 (δ^2) Gruis.

The Crane's shape is relatively easy to identify. First find the lengthy line of stars that starts with Beta (β) Gru and stretches to the northwest, ending with Gamma (γ) Gru. Beta lies in the main body of the bird, with the Delta^1 and Delta^2 pair marking the beginning of the Crane's long neck. The neck continues with another pair, Mu^1 (μ^1) and Mu^2 (μ^2), followed by Lambda (λ). Gamma pinpoints the bird's head and lies near the constellation's border with Piscis Austrinus the Southern Fish.

In the opposite direction from Beta, the triangle of stars Epsilon (ε), Eta, and Zeta (ζ) marks Grus' tail. The bird's wings run perpendicular to this extended line through Beta. The western wing ends at Alpha (α) and the eastern wing terminates with the Theta (θ) and Iota pair.

Grus first appeared in its current form in Johann Bayer's classic 1603 atlas, *Uranometria*, though he didn't invent it. Long ago, celestial cartographers deemed the stars of Grus as an extension of Piscis Austrinus. Ptolemy considered the star we know as Gamma Gru as marking the tip of the Southern Fish's tail, but Bayer's chart shows the bird and fish clearly separated. Not long after Bayer's atlas appeared, a few astronomers tried to turn the Crane into a flamingo and called the constellation Phoenicopterus. (In zoology, the flamingo belongs to the Phoenicopteridae family.) However, no one ever uses this name today.

Intriguingly, Comet Bennett wasn't the first well-known comet to pass through Grus. Ninety years earlier, the Great Southern Comet of 1880 visited the Crane. Observers reported that this dirty snowball from the outer solar system sported a spectacular tail.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. October 1
9 P.M. October 15
8 P.M. October 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

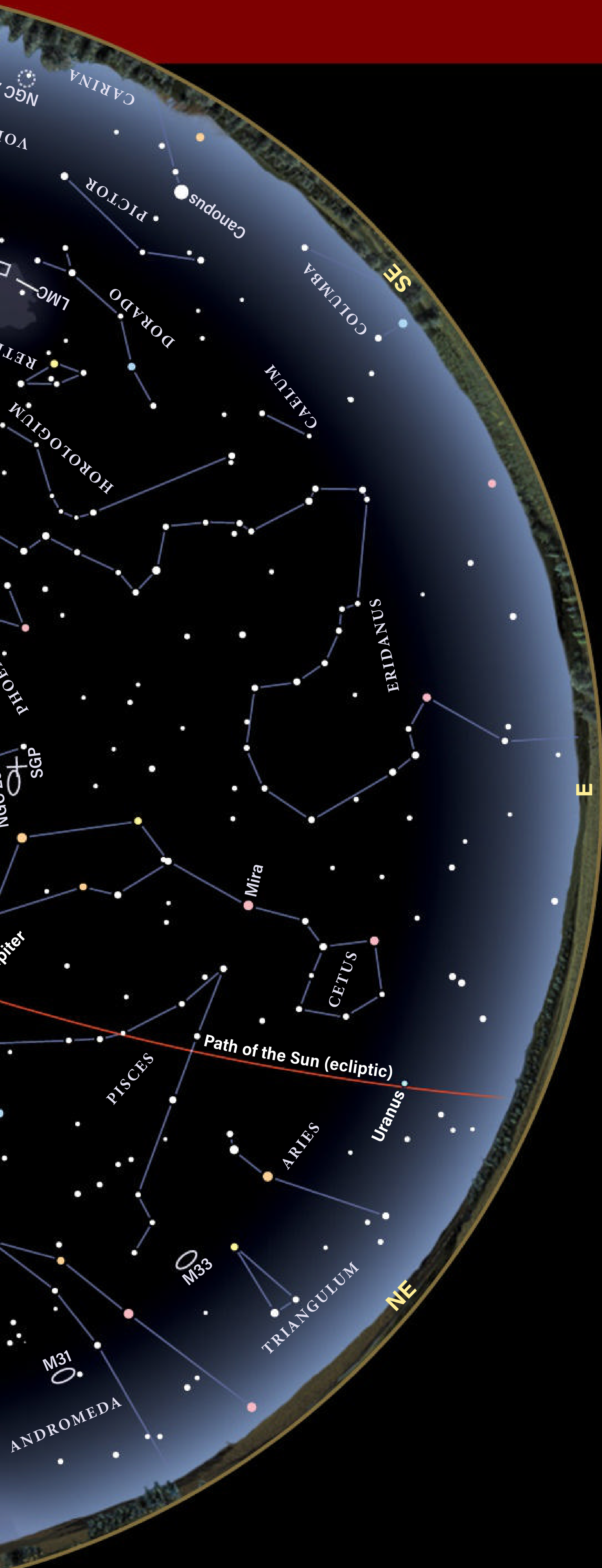
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



OCTOBER 2022

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1	Mercury is stationary, 15h UT
3	First Quarter Moon occurs at 0h14m UT
4	The Moon is at perigee (369,325 kilometers from Earth), 16h34m UT
5	The Moon passes 4° south of Saturn, 16h UT
7	Asteroid Vesta is stationary, 6h UT
8	The Moon passes 3° south of Neptune, 3h UT
	The Moon passes 2° south of Jupiter, 18h UT
	Pluto is stationary, 18h UT
	Mercury is at greatest western elongation (18°), 21h UT
9	Full Moon occurs at 20h55m UT
12	The Moon passes 0.8° north of Uranus, 7h UT
15	The Moon passes 4° north of Mars, 5h UT
17	The Moon is at apogee (404,328 kilometers from Earth), 10h20m UT
	Last Quarter Moon occurs at 17h15m UT
19	Asteroid Juno is stationary, 0h UT
21	Orionid meteor shower peaks
22	Venus is in superior conjunction, 21h UT
23	Saturn is stationary, 9h UT
25	New Moon occurs at 10h49m UT; partial solar eclipse
29	The Moon is at perigee (368,291 kilometers from Earth), 14h36m UT
30	Mars is stationary, 11h UT

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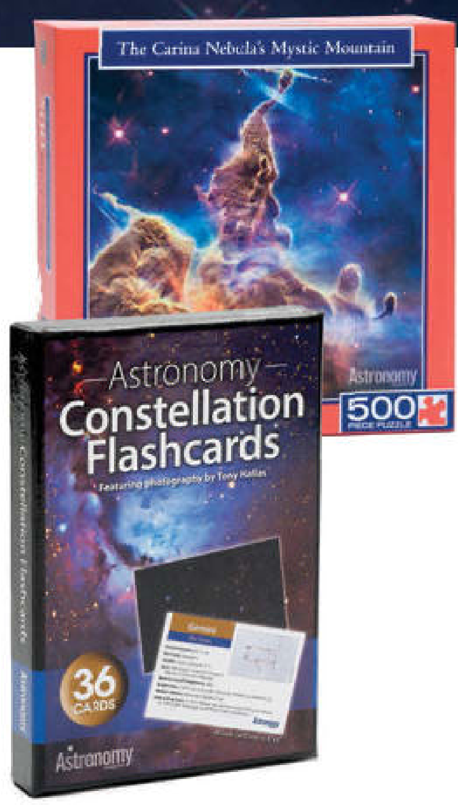

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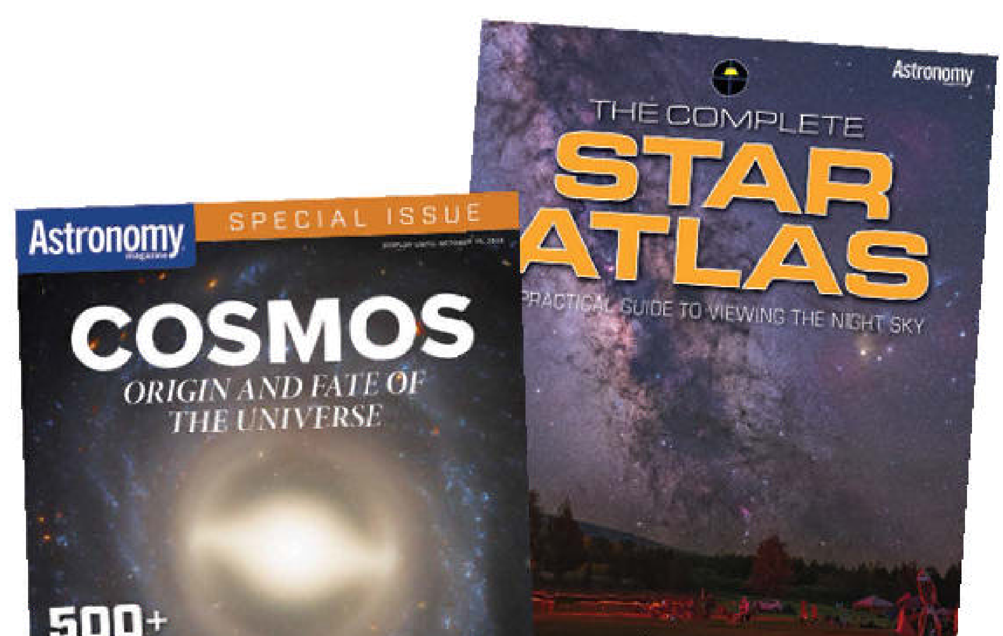

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